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[54] **PLASMA PROCESS APPARATUS**

[75] Inventors: **Mitsuaki Komino**, Tokyo; **Yoichi Ueda**, Yokohama; **Youichi Deguchi**, Tokyo; **Satoru Kawakami**, Sagamihara, all of Japan

[73] Assignee: **Tokyo Electron Limited**, Tokyo, Japan

[21] Appl. No.: **183,406**

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Feb. 10, 1993	[JP]	Japan	5-045783
Feb. 16, 1993	[JP]	Japan	5-049994
Feb. 16, 1993	[JP]	Japan	5-050226
Feb. 20, 1993	[JP]	Japan	5-055090
Feb. 24, 1993	[JP]	Japan	5-060988

[51] **Int. Cl.**^{6} **H05H 1/00**

[52] **U.S. Cl.** .... **156/345**; 204/298.06; 204/298.08; 204/298.09; 204/298.15; 204/298.34; 204/298.03; 204/298.32; 118/723 E; 118/724; 118/728; 216/61; 216/71

[58] **Field of Search** .... 156/345, 627.1; 204/298.03, 298.32, 298.09, 298.34, 298.06, 298.15, 298.08; 118/723 E, 723 ER, 725, 724, 728; 216/61, 71

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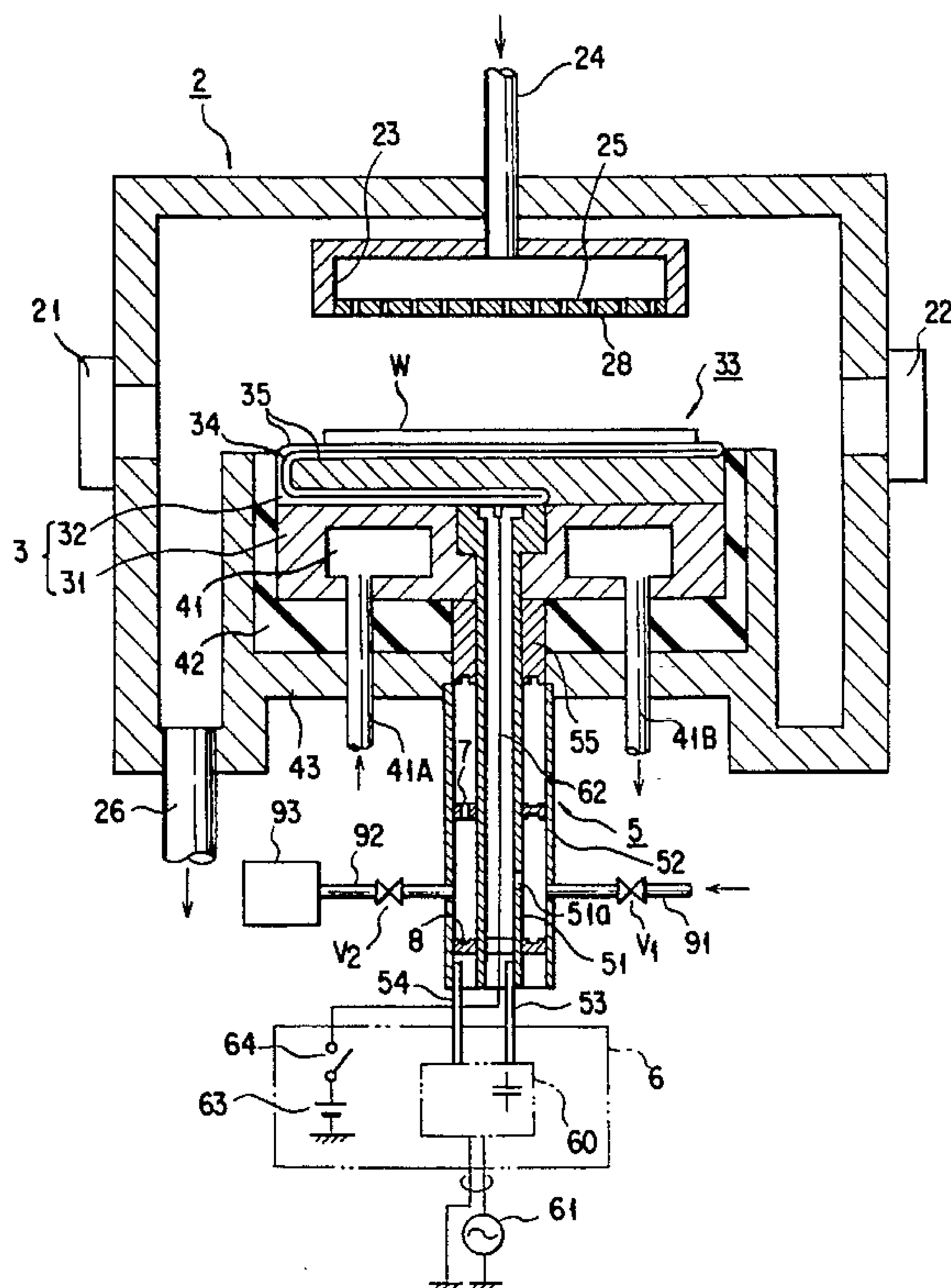
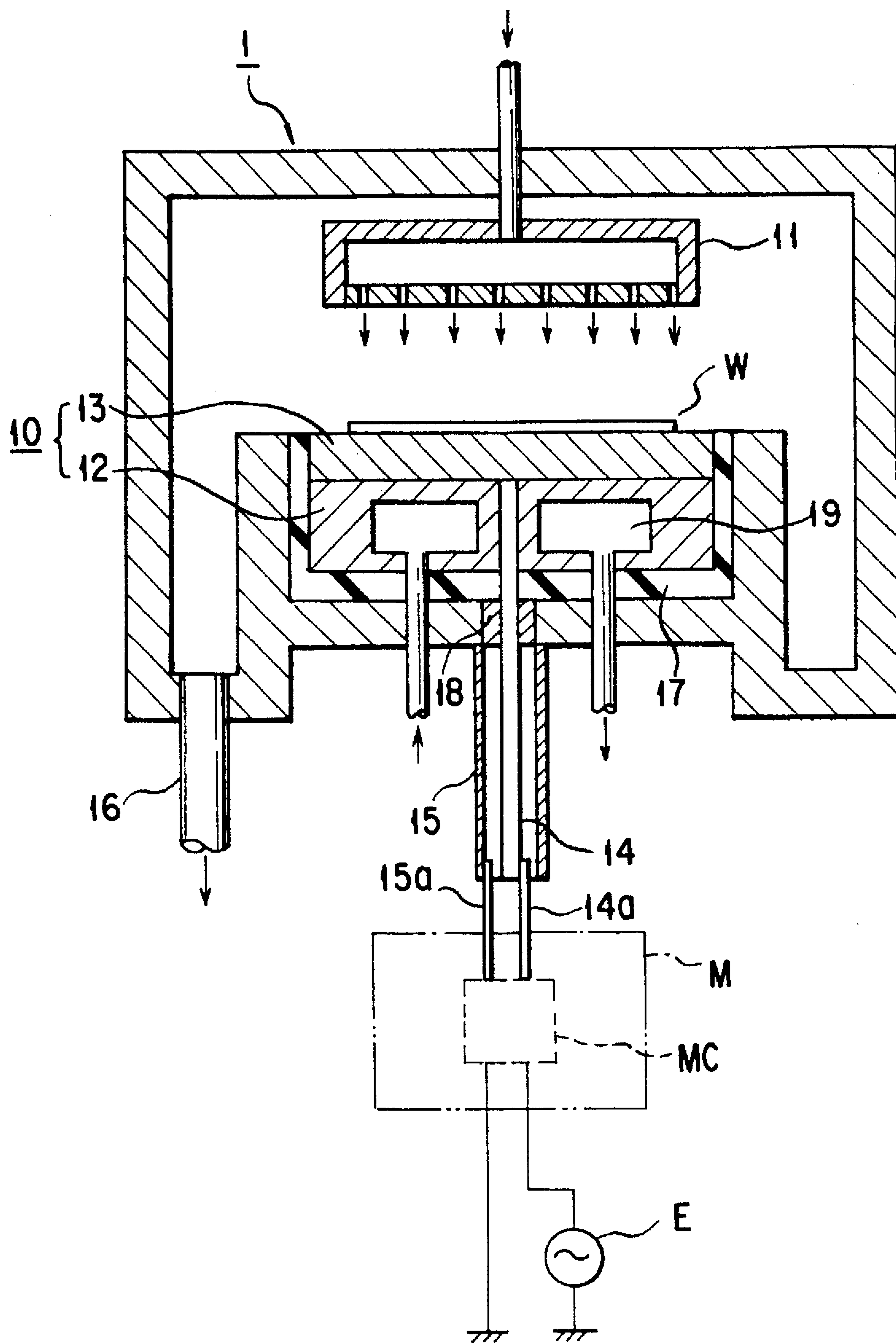
Primary Examiner—Thi Dang
Attorney, Agent, or Firm—Oblon, Spivak, McClelland, Maier, & Neustadt

[57] **ABSTRACT**

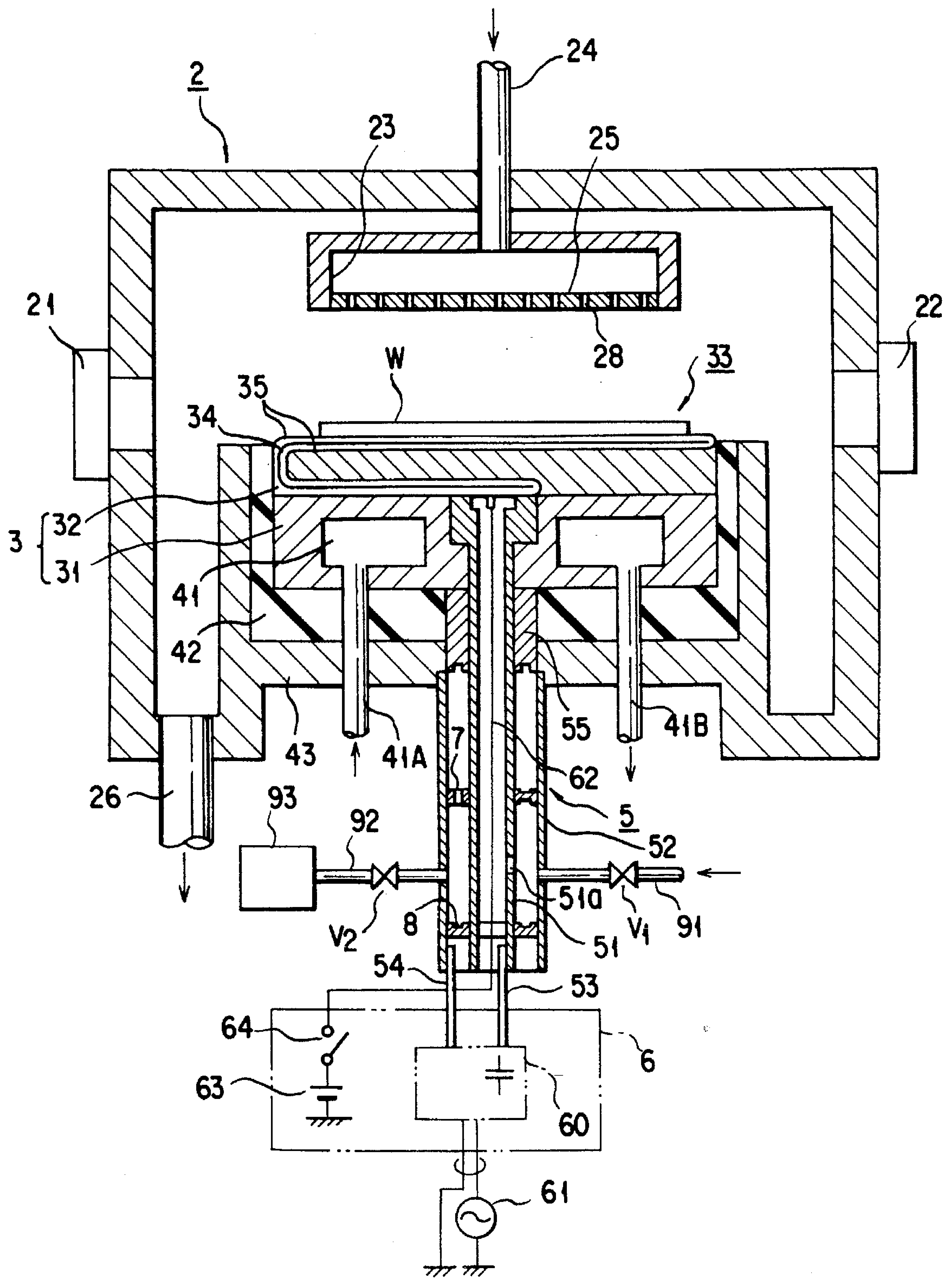
The present invention provides a plasma process apparatus wherein RF power is applied to a process gas, thereby to convert the gas into plasma for processing an object, the apparatus having a process chamber, an upper electrode located in the process chamber and having a gas-supplying section for supplying a process gas, a lower electrode located in the process chamber, having a cooling means, and opposing the upper electrode, for supporting an object, and RF power supplying means electrically connected to the lower electrode, protruding from the process chamber and connected to a RF power supply, for supplying RF power between the upper and lower electrodes, wherein the RF power supplying means includes, an outer conductive pipe surrounding the inner conductive rod and spaced therefrom, and a fixing member inserted between the inner conductive rod and the outer conductive pipe and having concaves and convexes, the inner conductive rod and the outer conductive pipe being electrically connected to an RF power supply source.

17 Claims, 15 Drawing Sheets





F I G. 1
(PRIOR ART)



F I G. 2

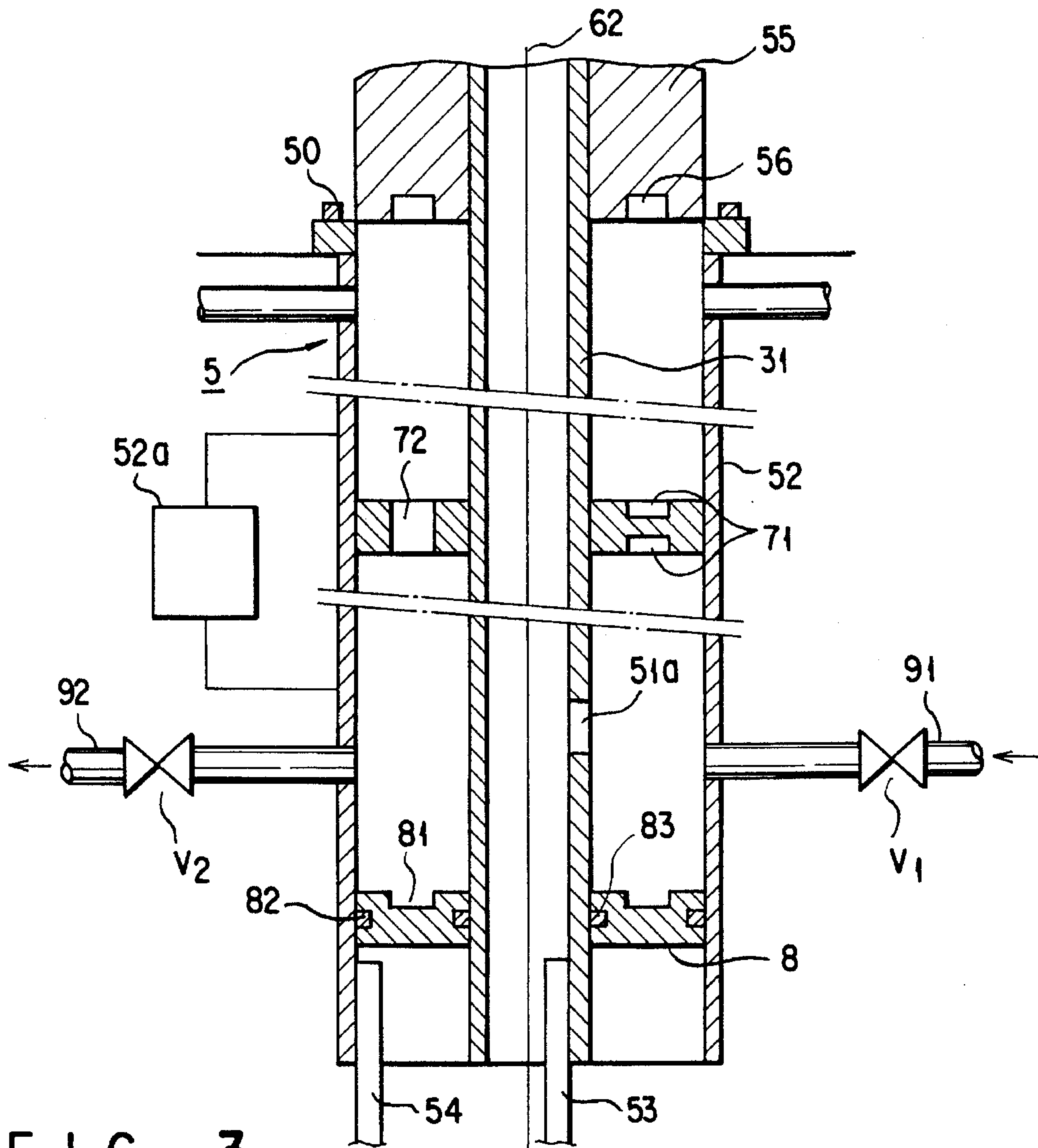


FIG. 3

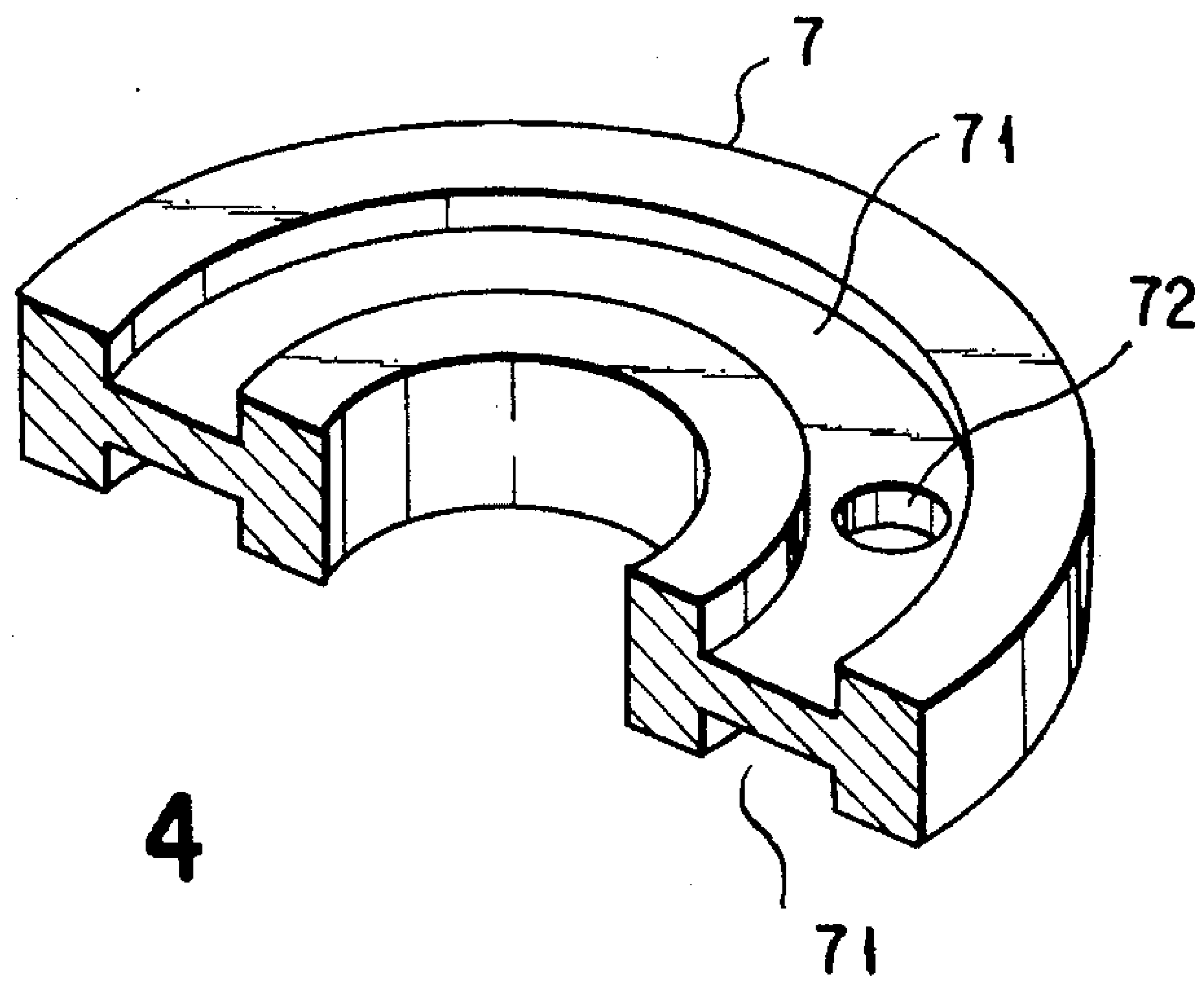
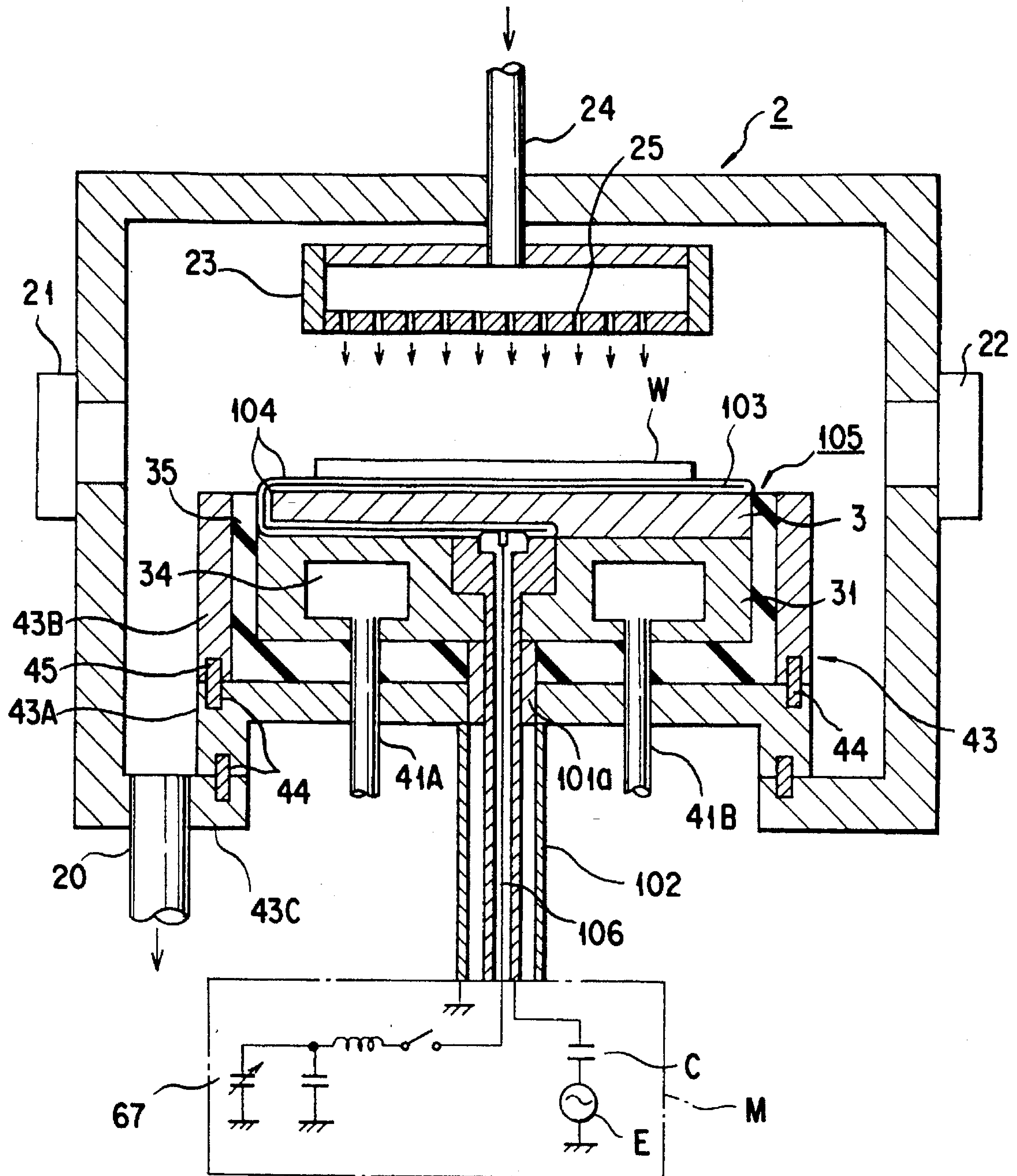


FIG. 4



F I G. 5

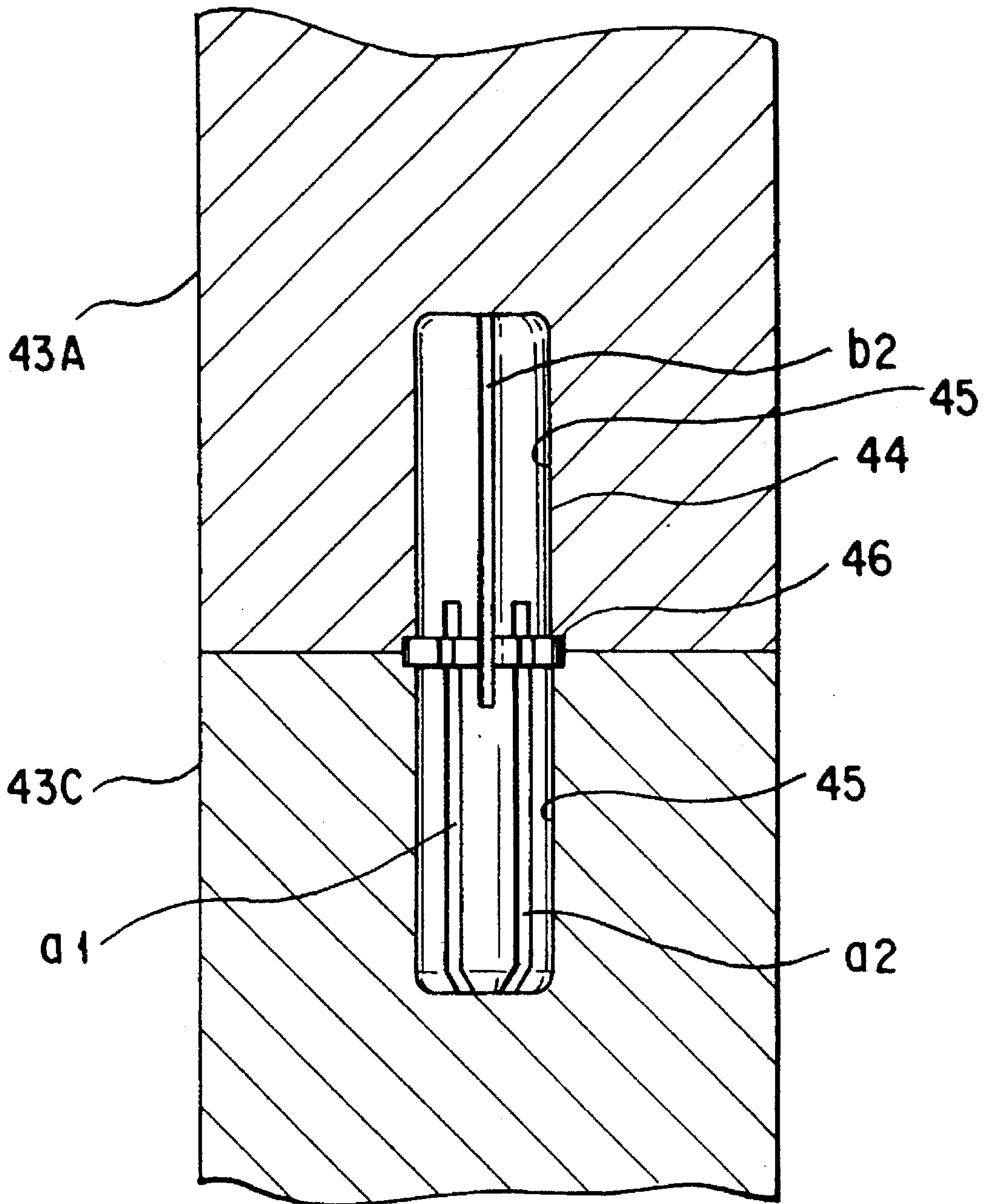


FIG. 6

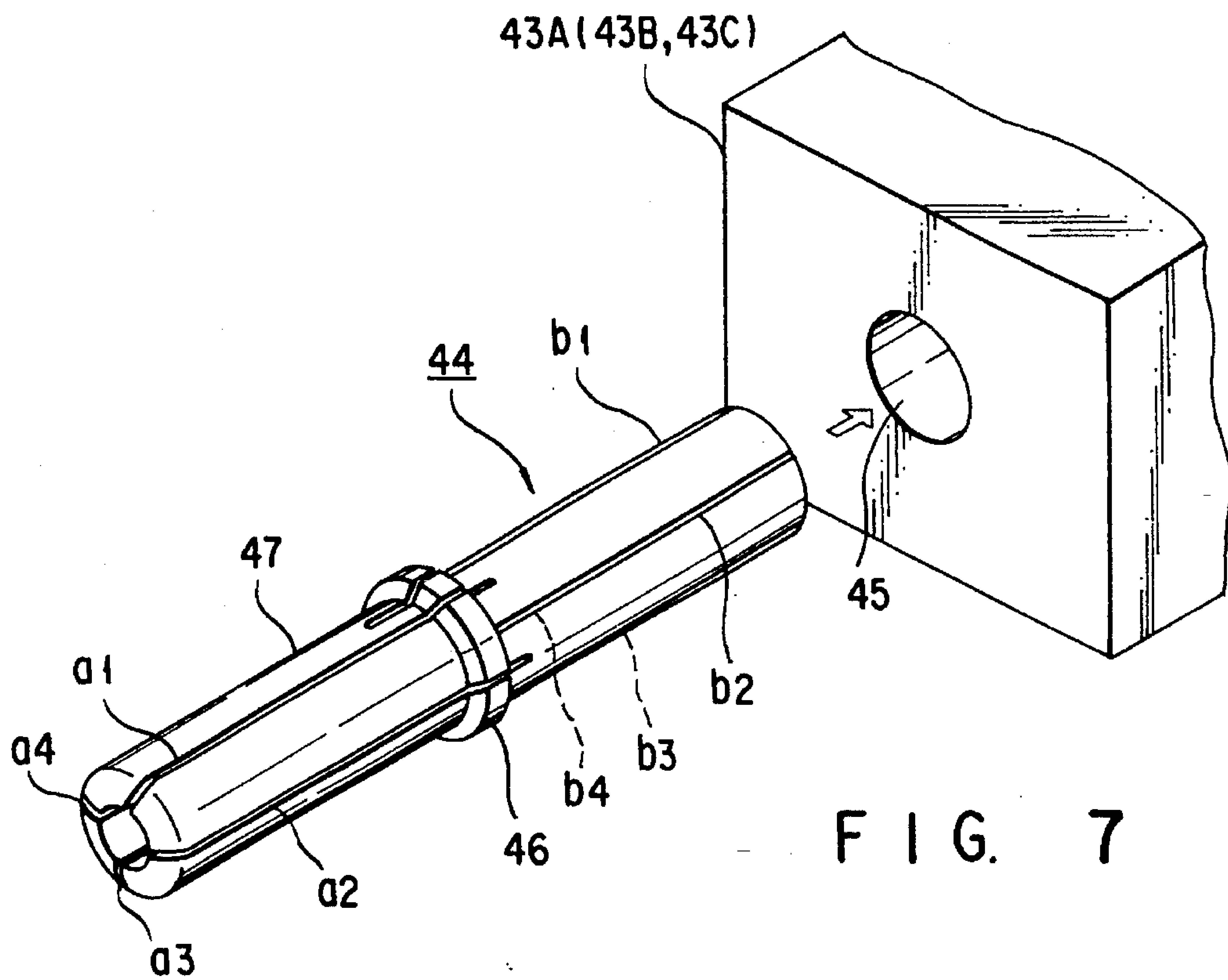


FIG. 7

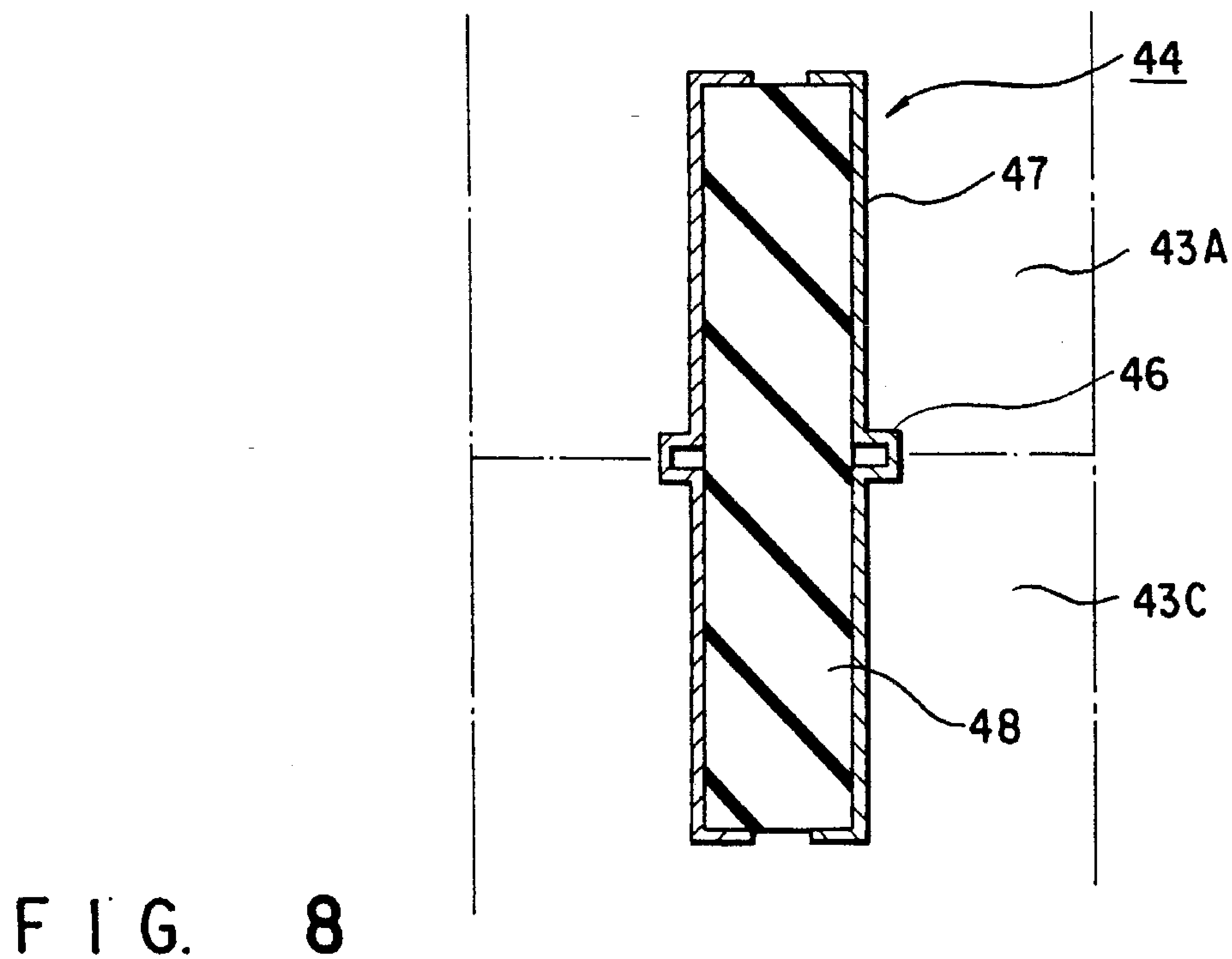


FIG. 8

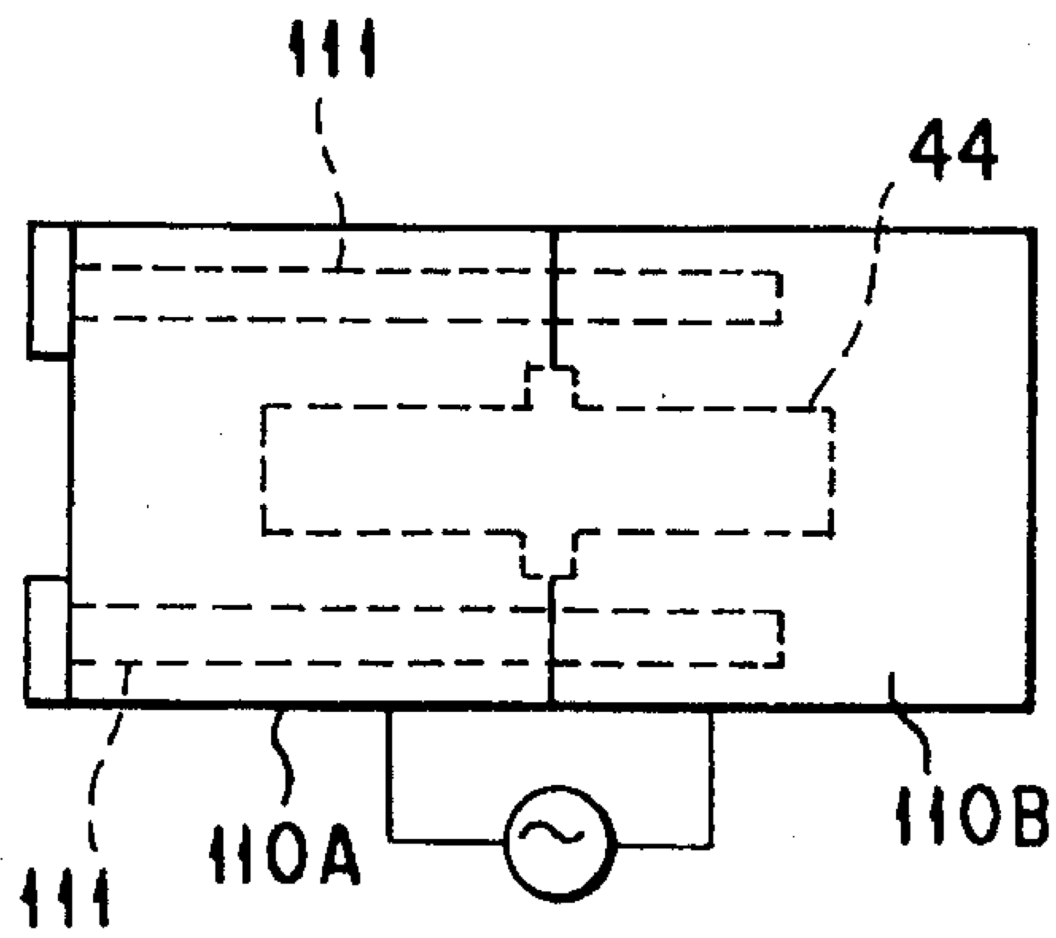


FIG. 9A

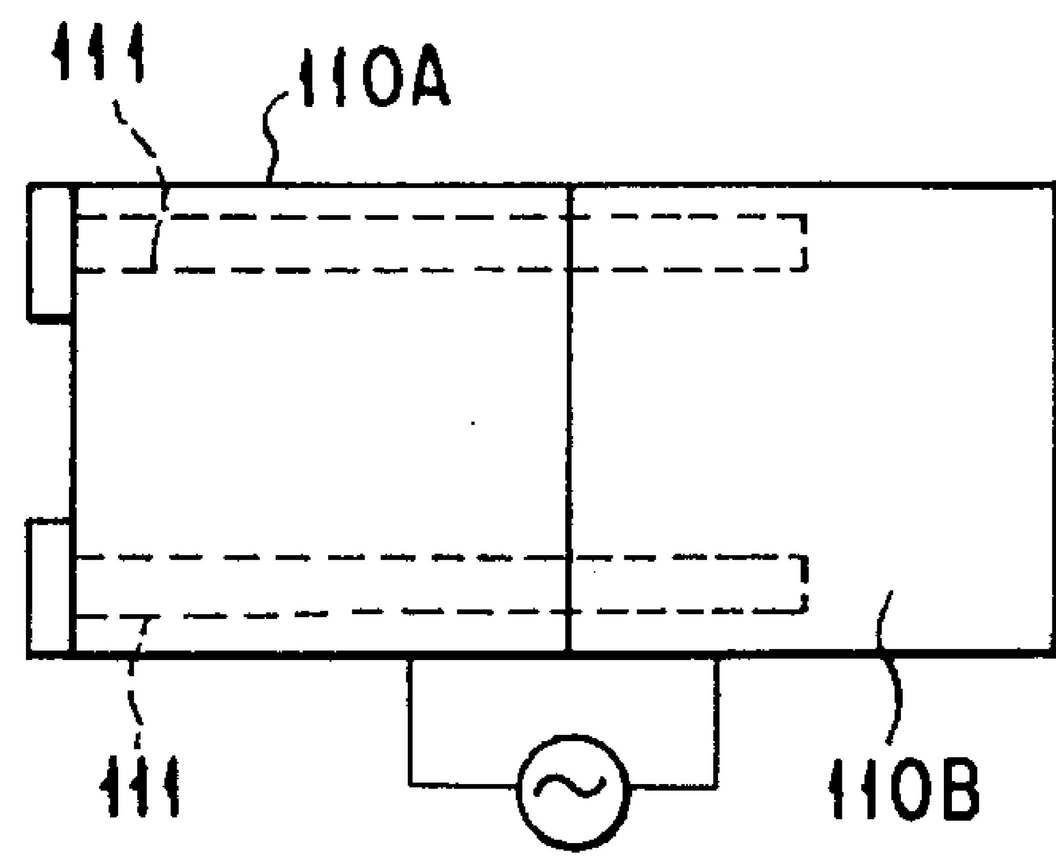


FIG. 9B

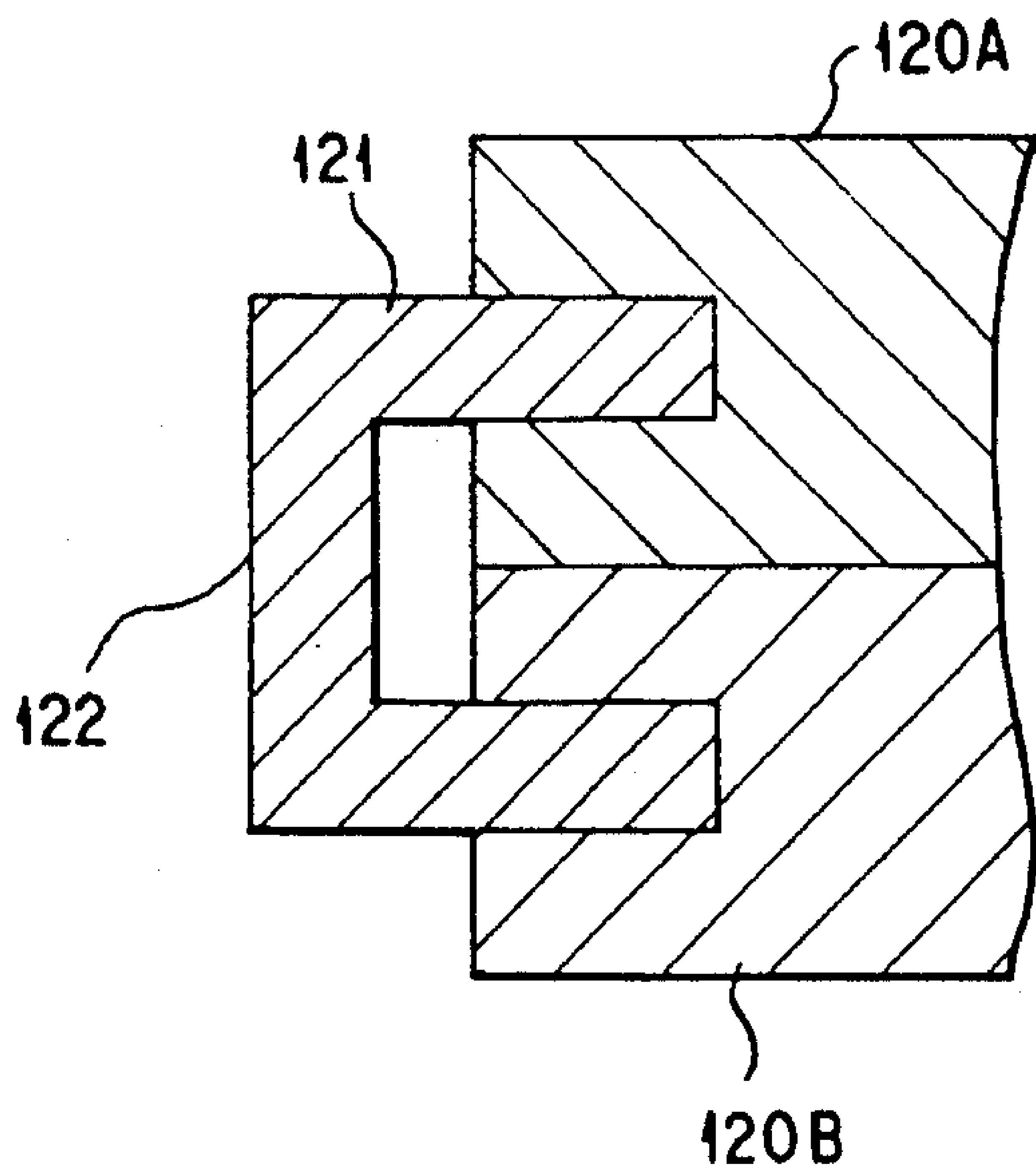


FIG. 10

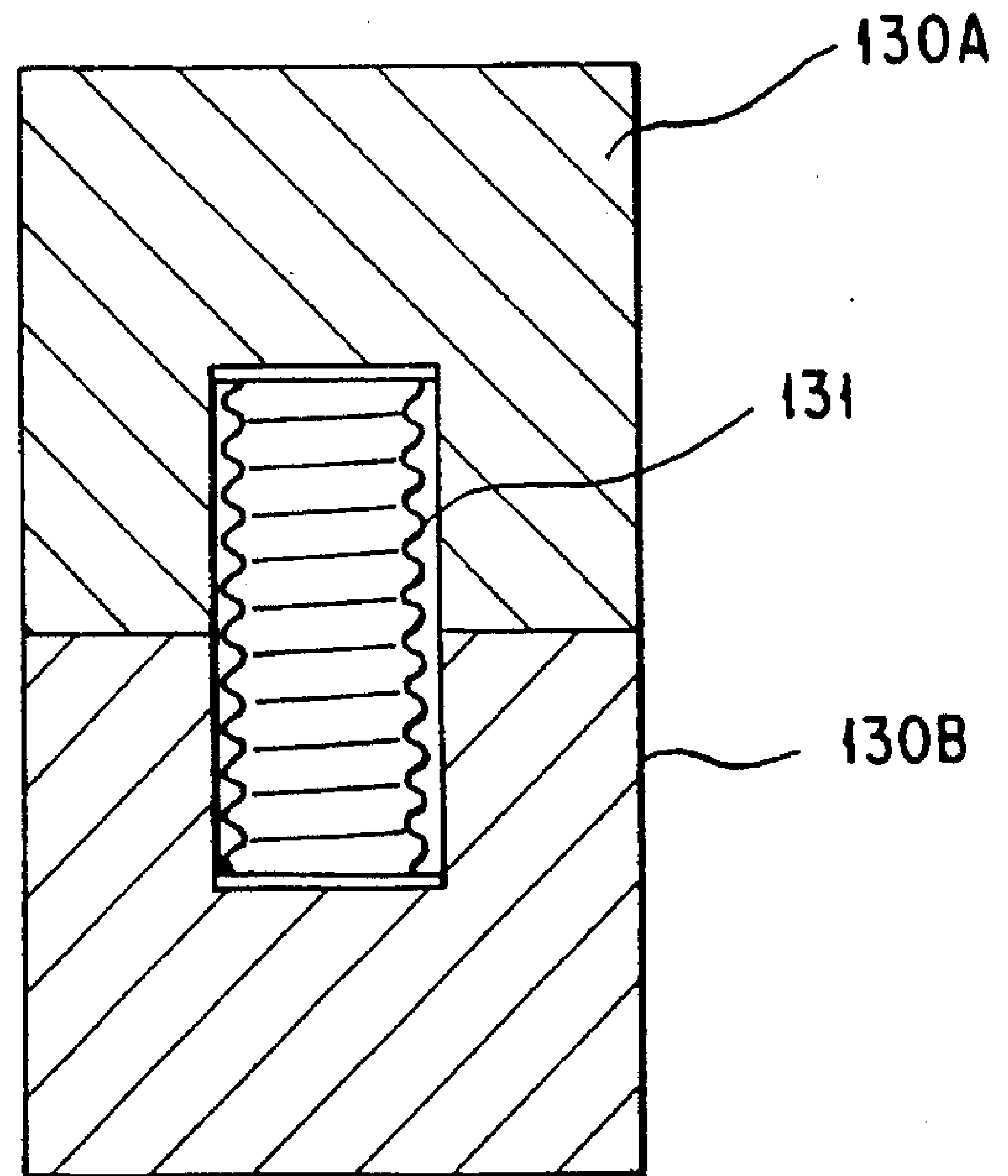
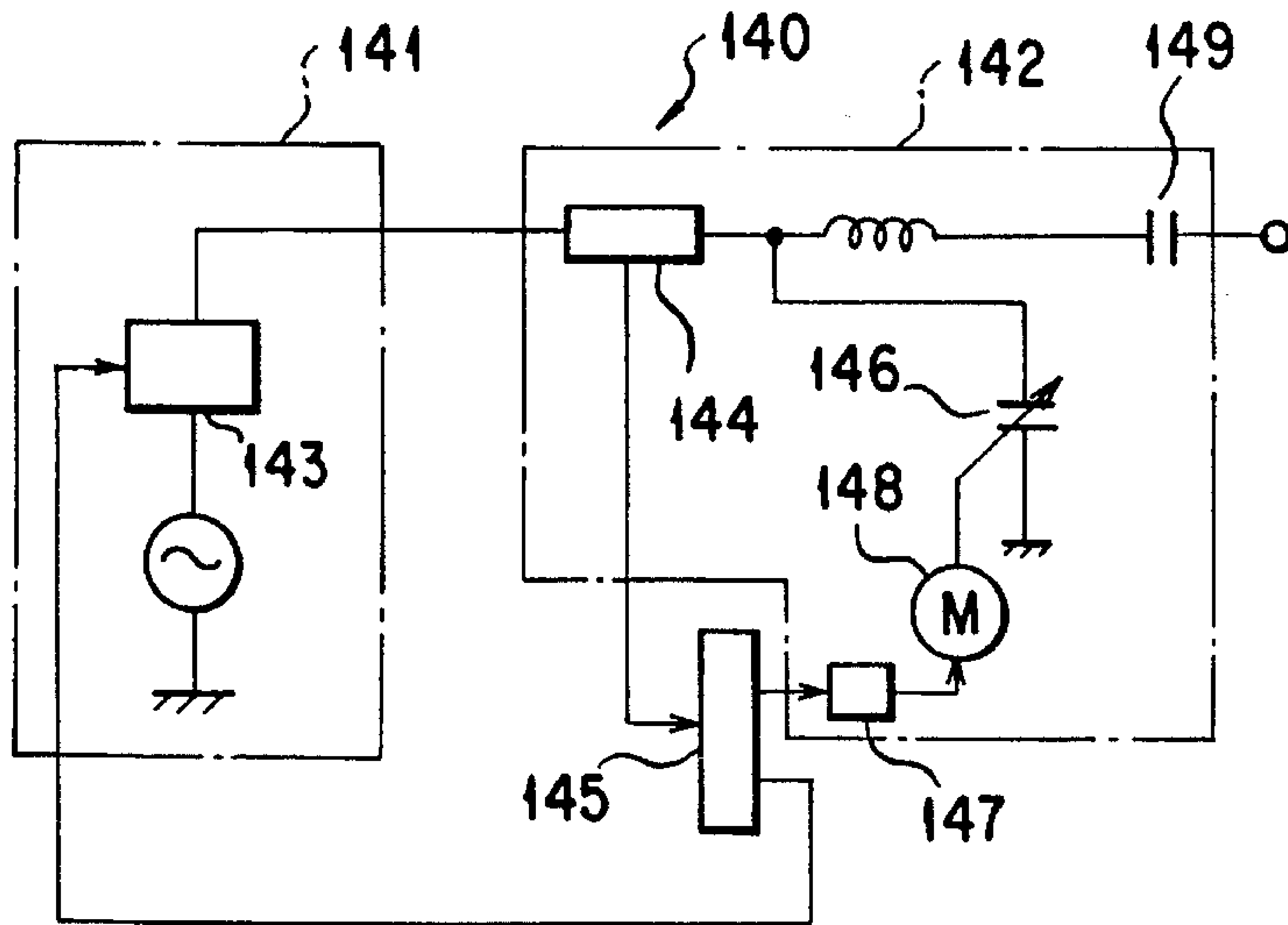
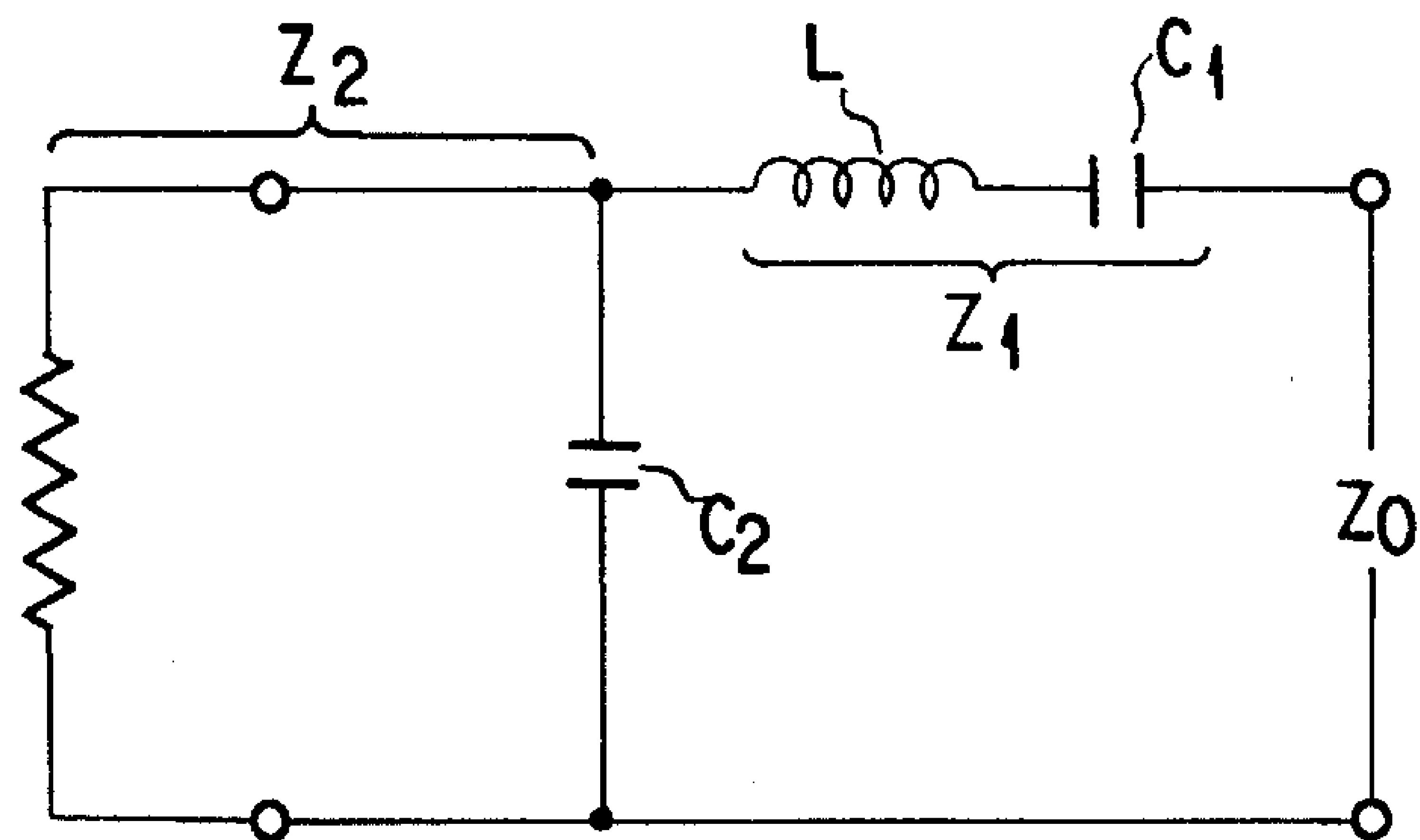


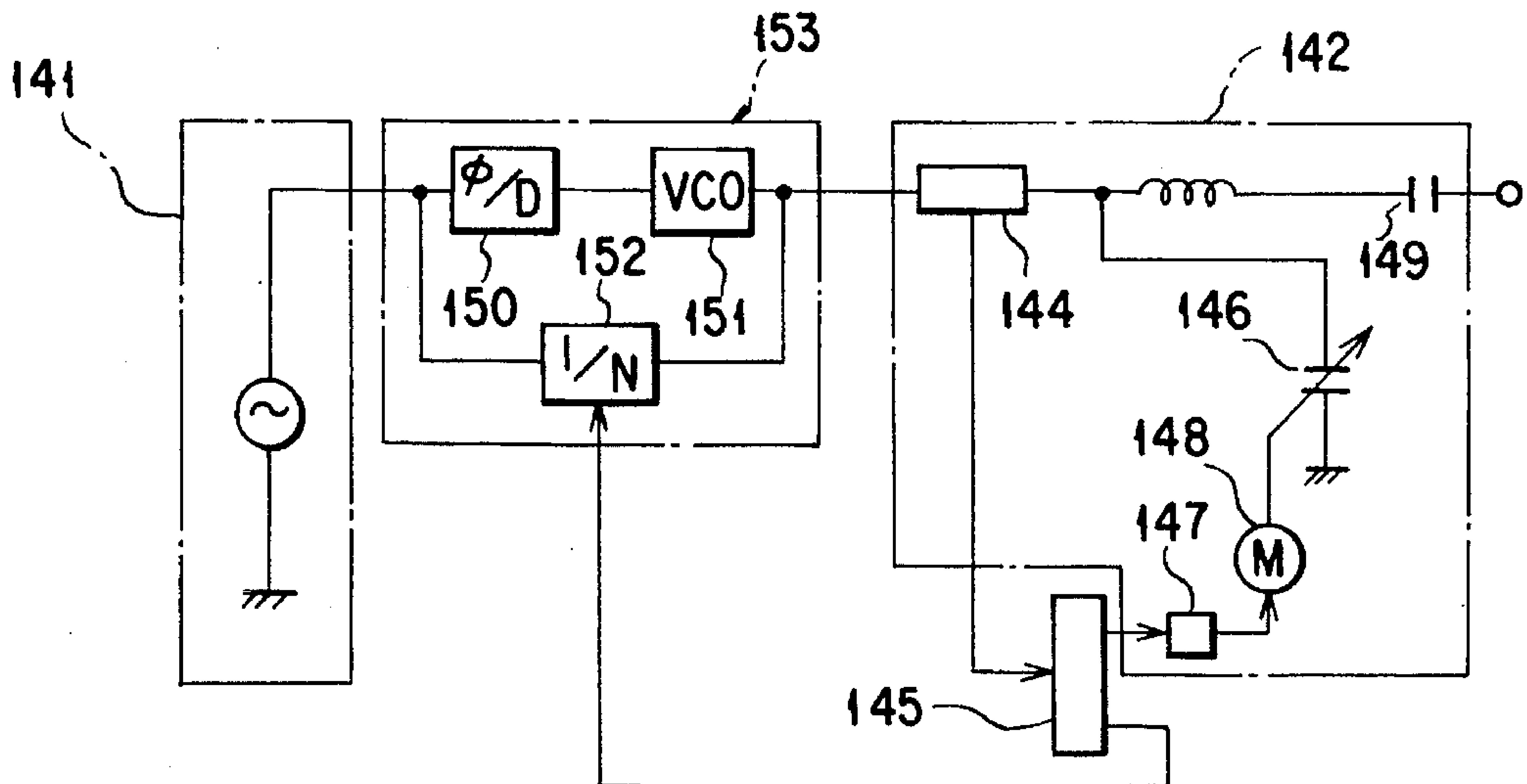
FIG. 11



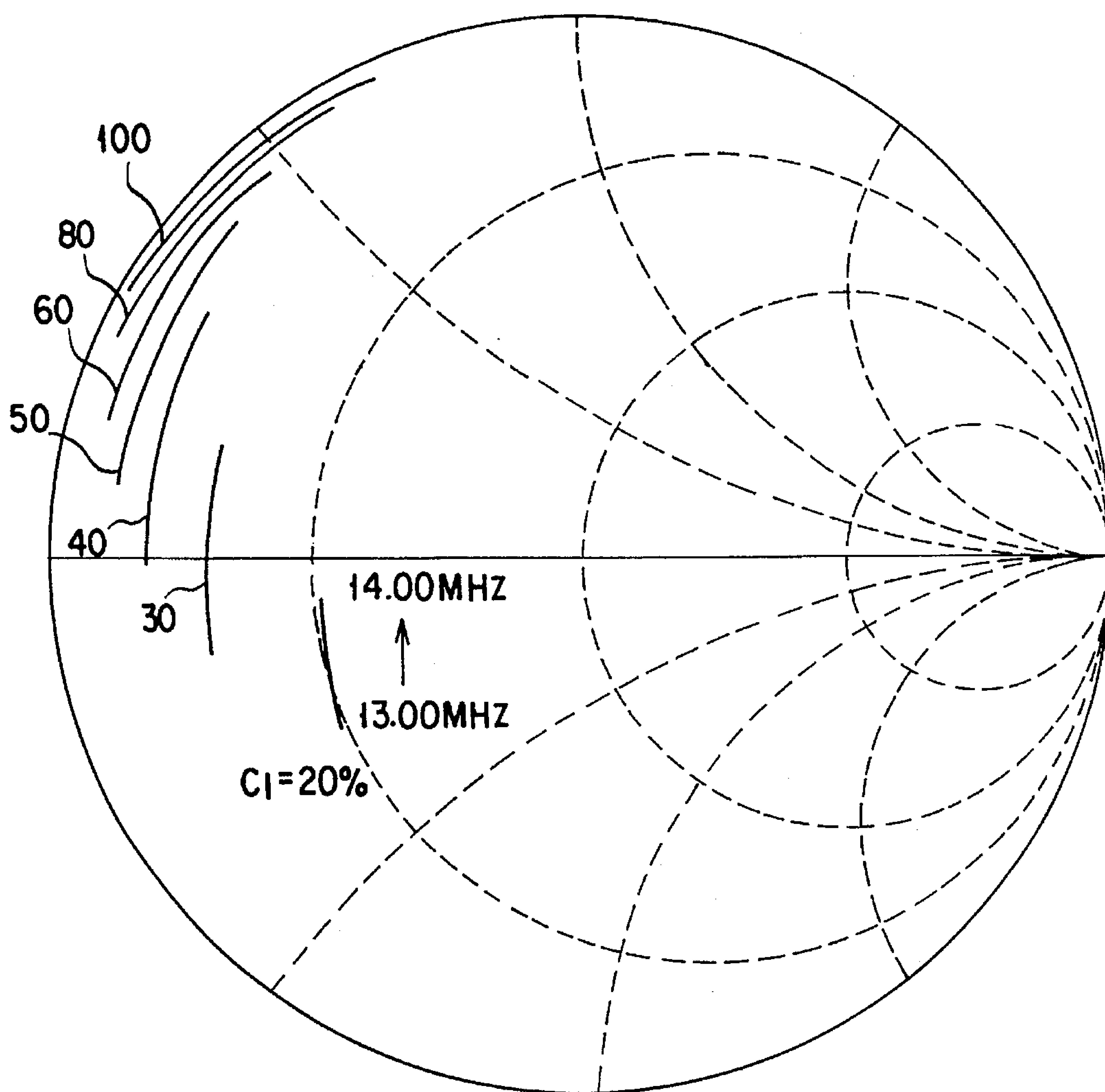
F I G. 12

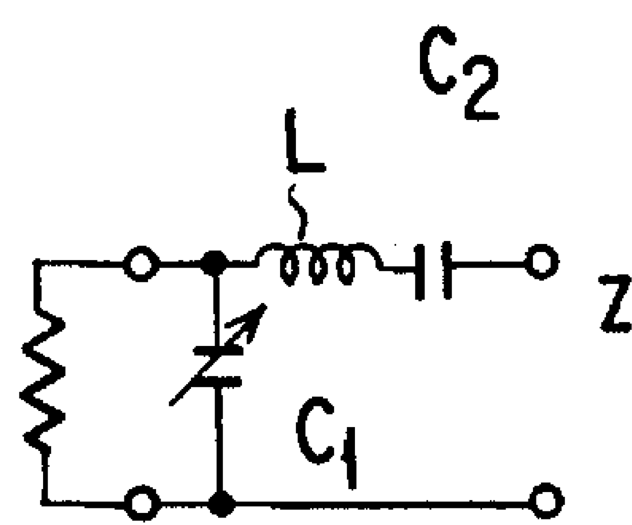


F I G. 13



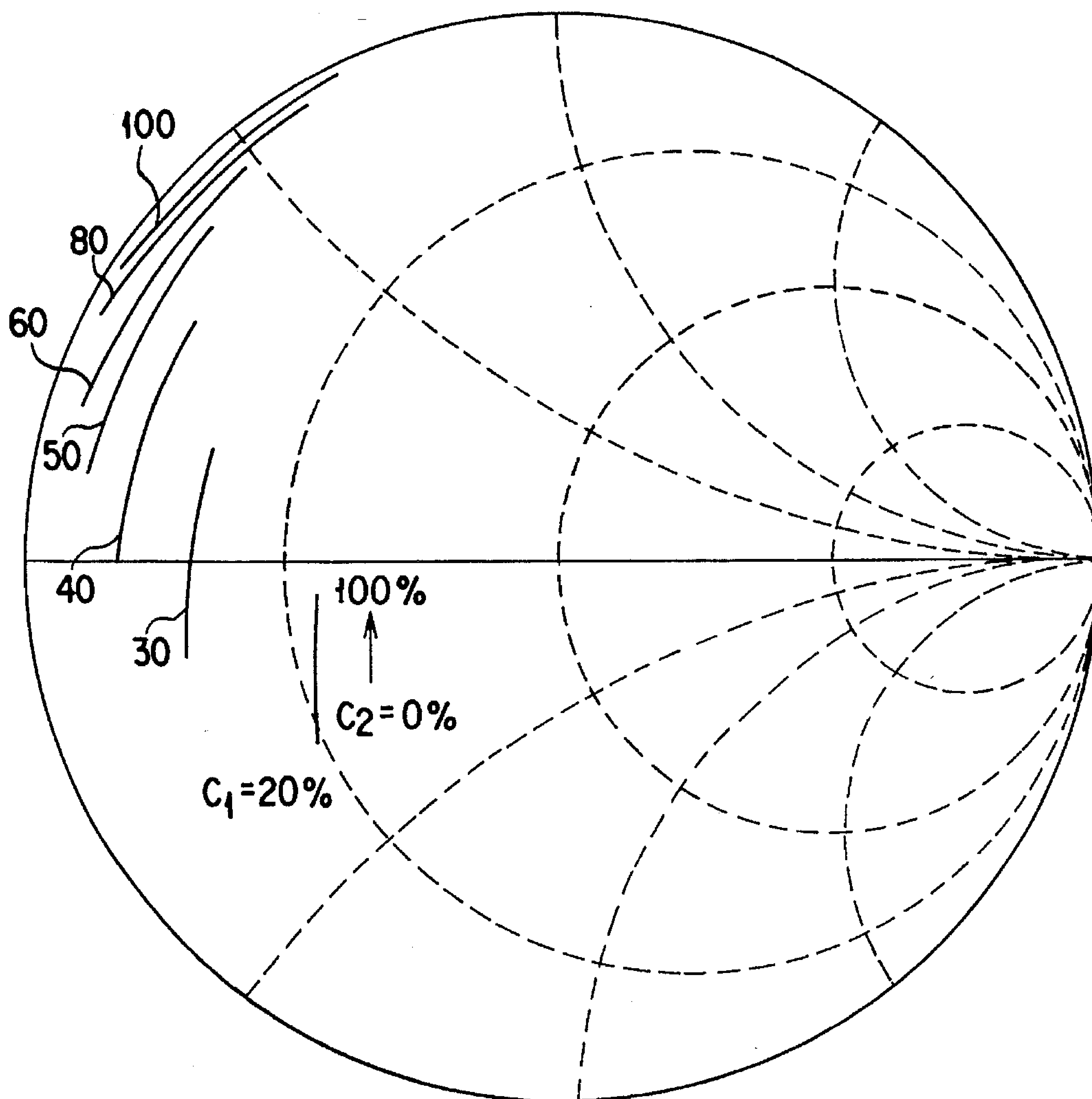
F I G. 16

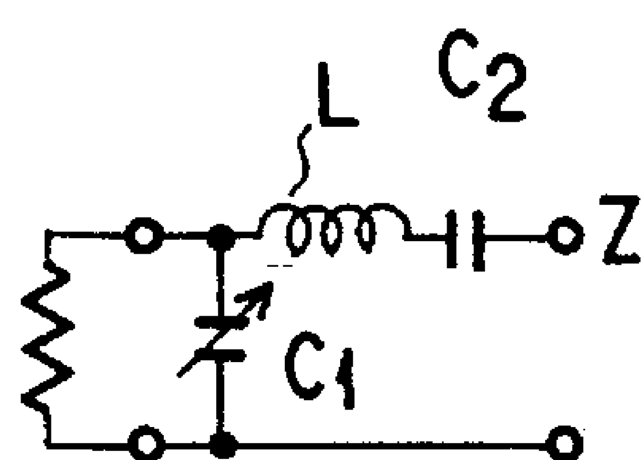




C_1	C_2	f
20	CONSTANT	13.00
30		
40		14.00
50		MHZ
60		
80		
100		

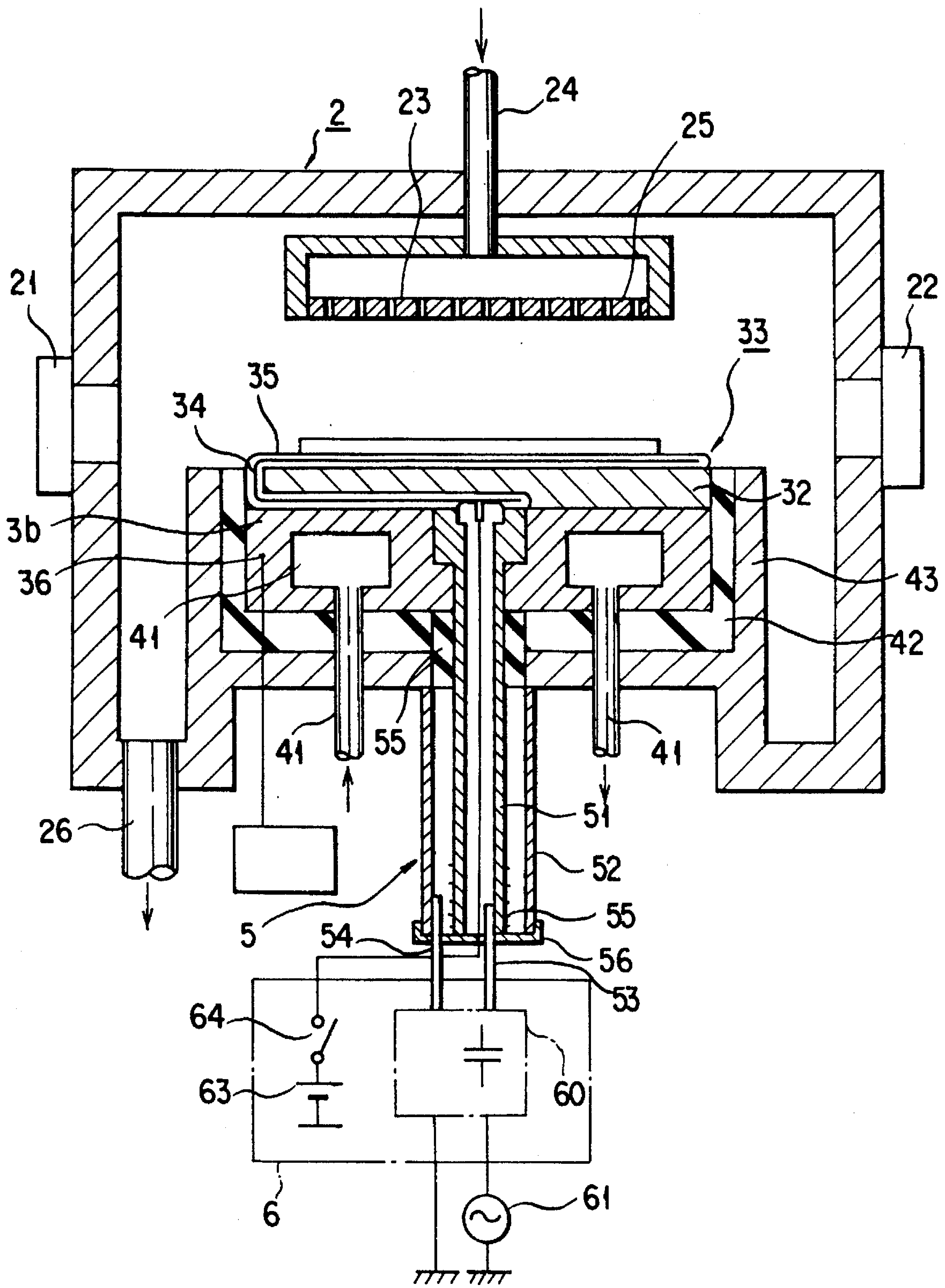
FIG. 14





C_1	C_2	f
20	CHANGE	CONSTANT
30	(0~100%)	(13.56MHZ)
40		
50		
60		
80		
100		

FIG. 15



F I G. 17

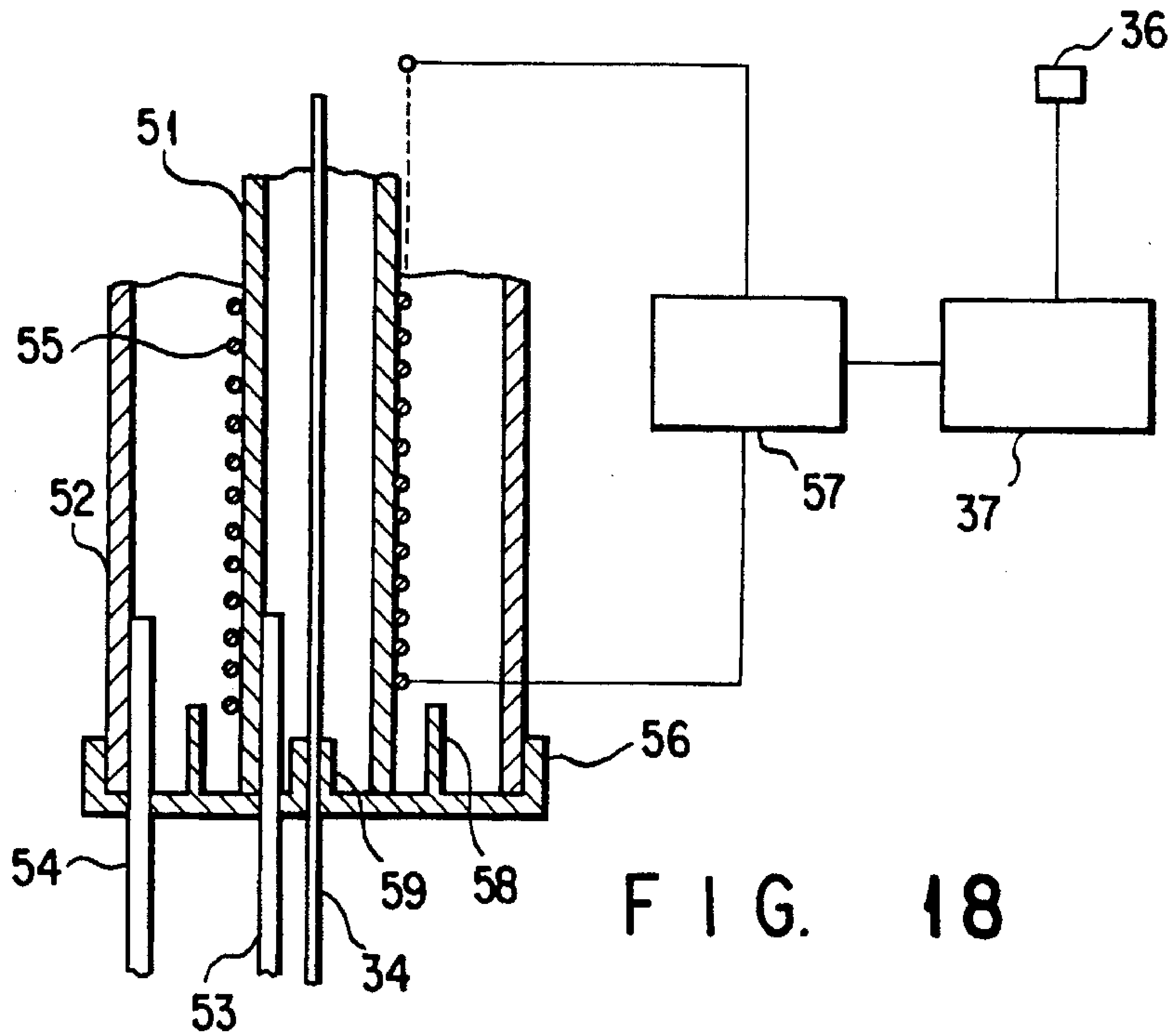


FIG. 18

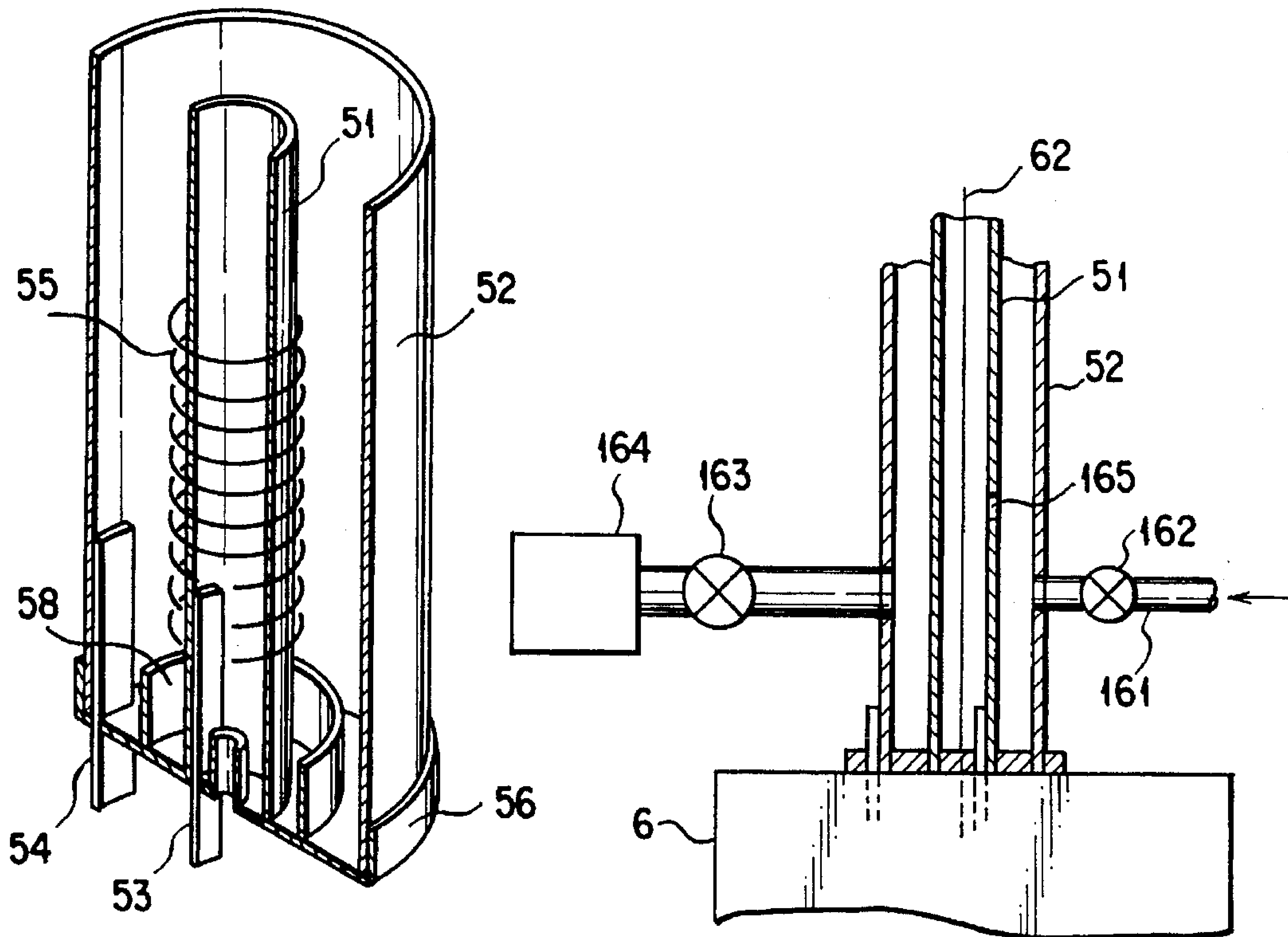
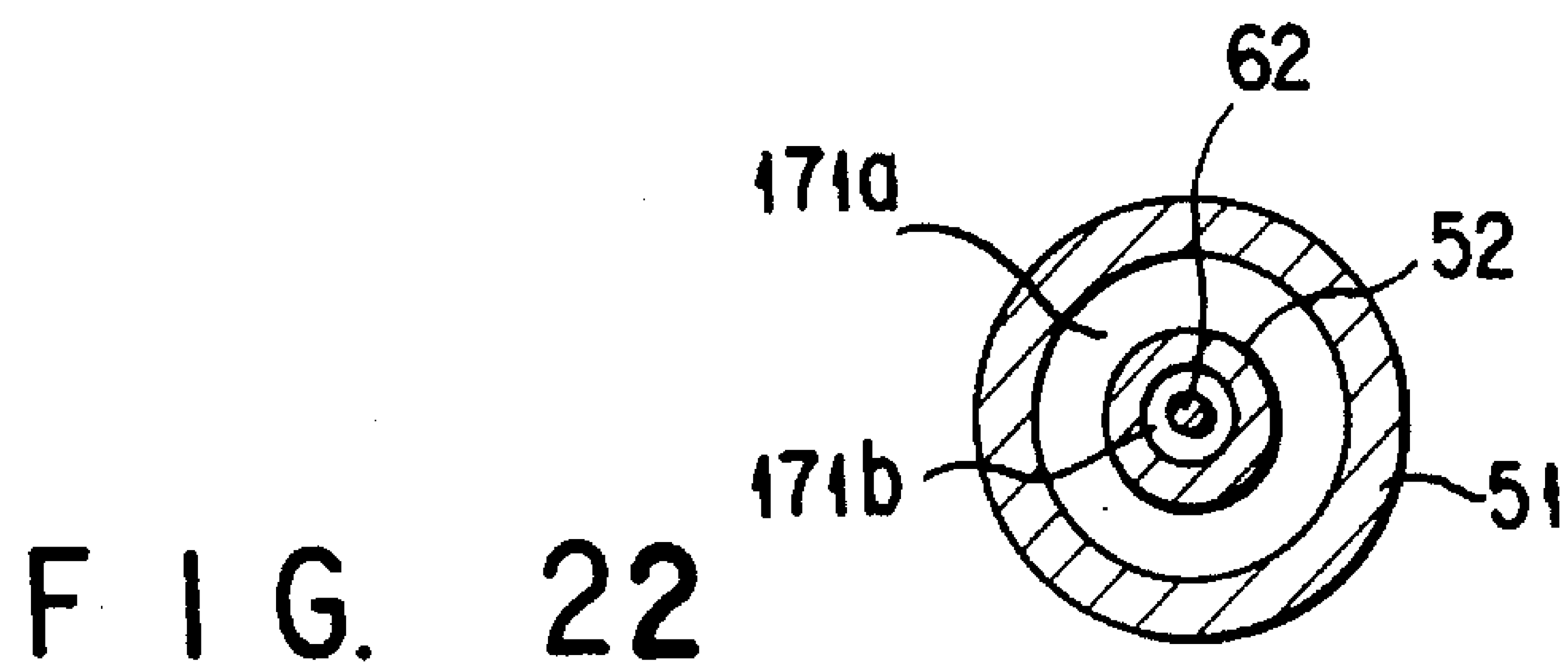


FIG. 19

FIG. 20

F I G. 21



F I G. 22

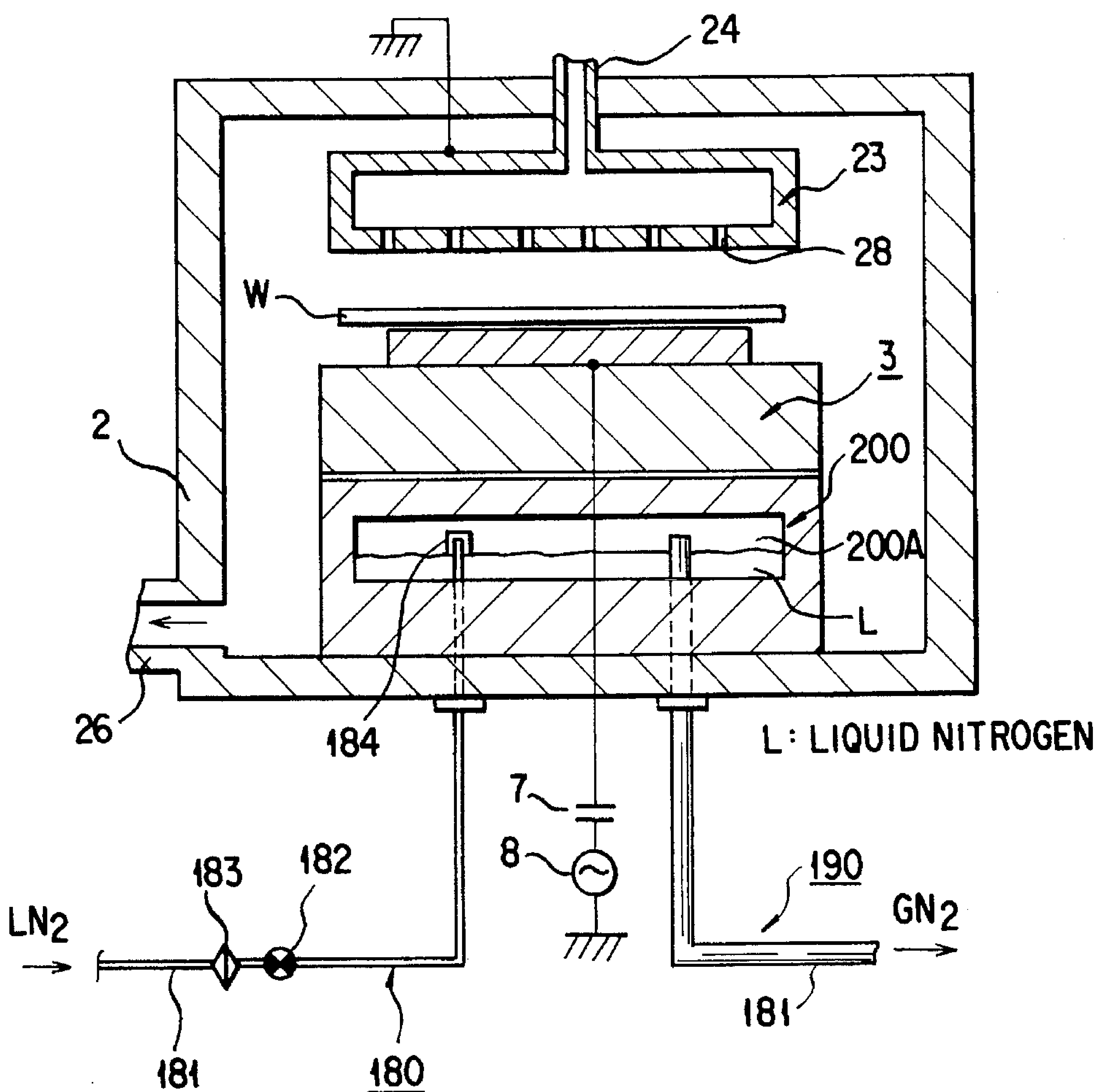


FIG. 23

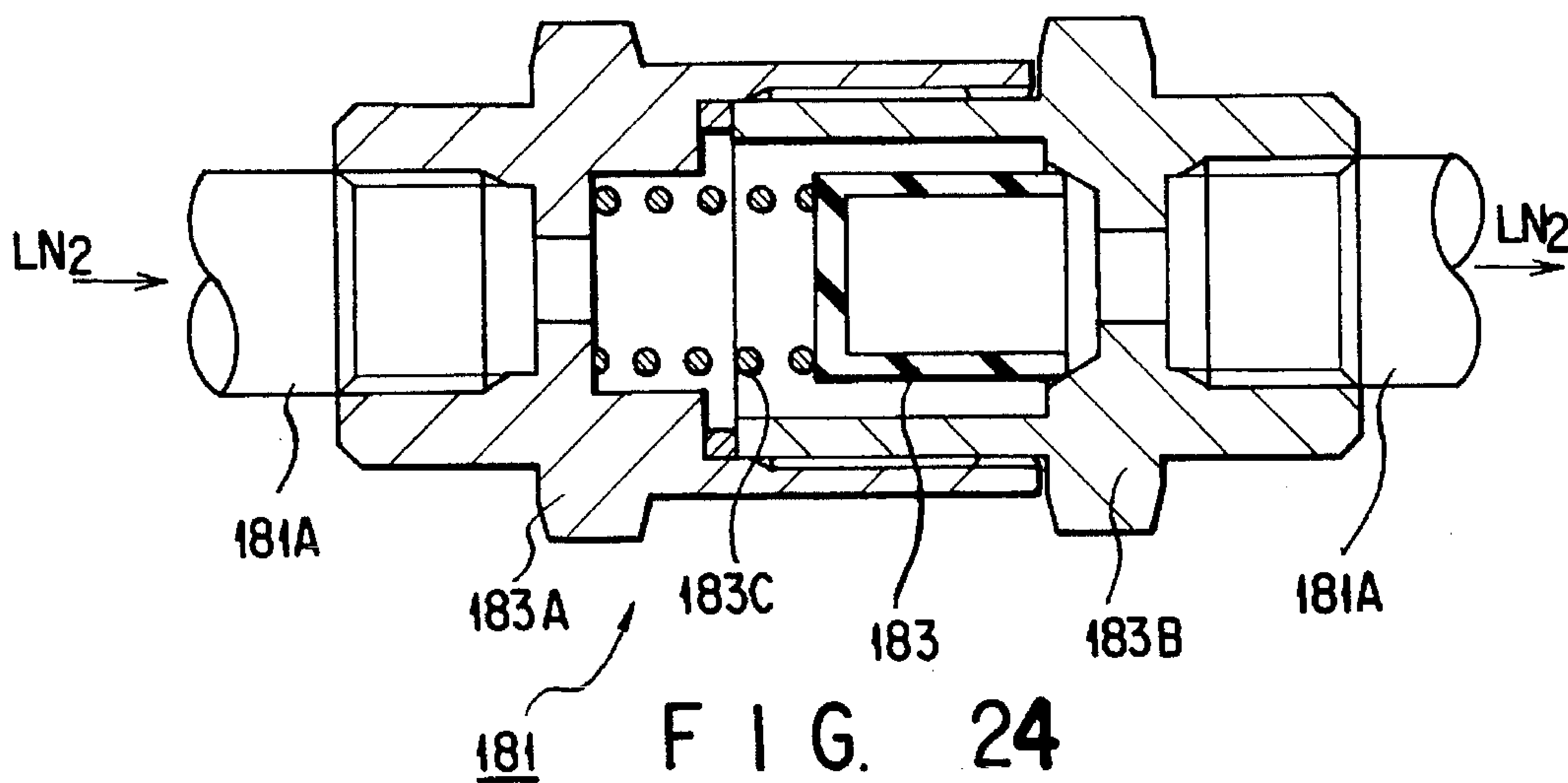
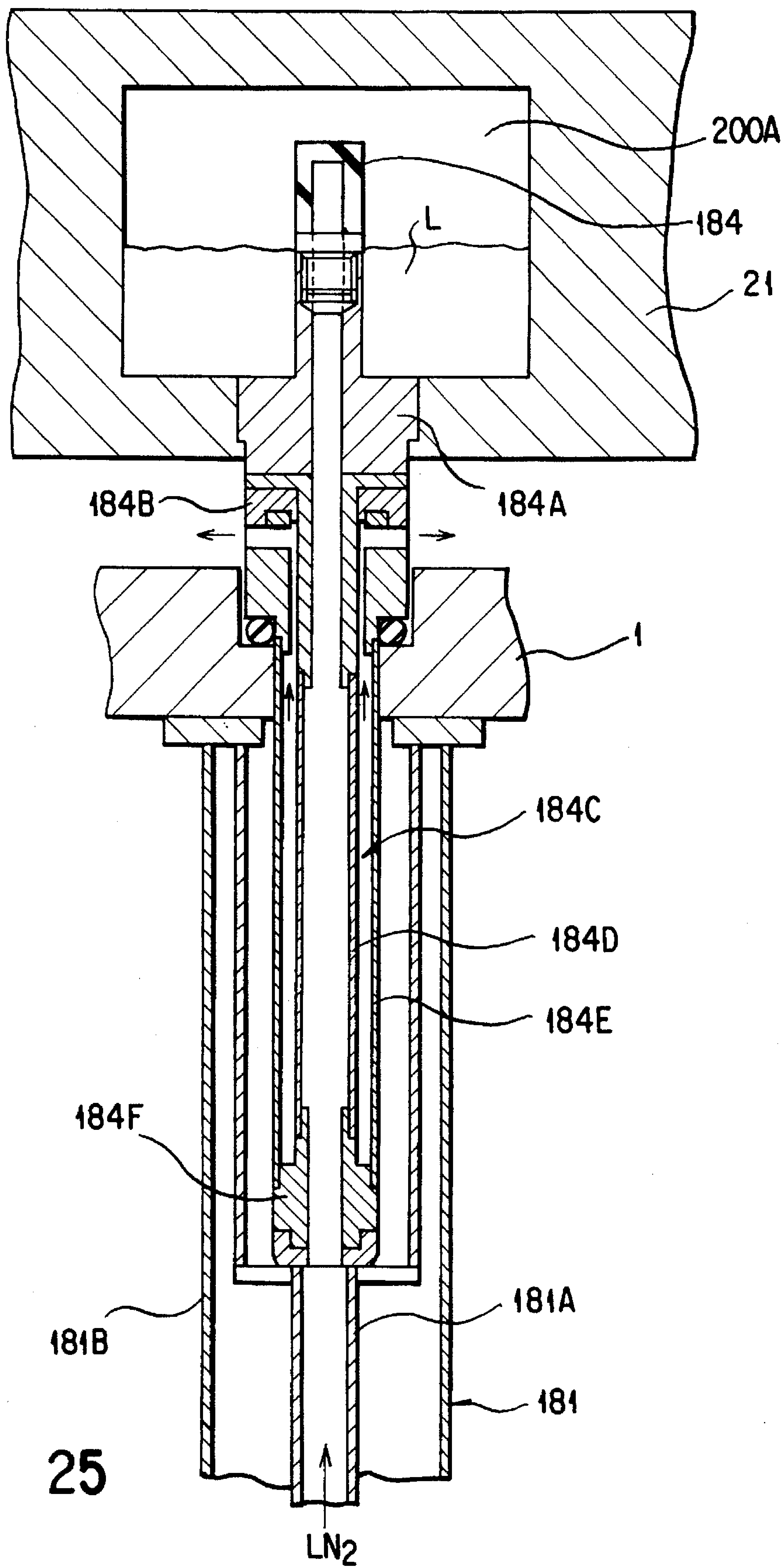


FIG. 24



F I G. 25

PLASMA PROCESS APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a plasma process apparatus.

2. Description of the Related Art

As is known, active species such as ions, complex ions, and radicals are present in a plasma obtained by electrically discharging a certain type of gas, and surface treatment of a semiconductor wafer can be presented as one of the fields in which these active specifies are used. For example, a process performed by using a plasma allows process control with high precision. For this reason, in the manufacturing process of a semiconductor wafer, plasma processes are used to perform etching and formation of various films.

As one of methods of generating a plasma, a method of applying RF power to a process gas is available. A plasma process apparatus, e.g., a signal wafer processing type etching apparatus, using this method has a lower electrode disposed in a process chamber having an airtight seal structure, and an upper electrode serving as a gas supply portion and disposed to oppose the lower electrode. This apparatus is designed to generate a plasma by applying RF power between the upper and lower electrodes so as to etch the surface of an object to be processed, e.g., a semiconductor wafer, placed on the lower electrode.

In such a conventional plasma process apparatus, a coaxial cable is used as a means for connecting a lower electrode to an RF power supply. However, a cumbersome operation is required to connect a shielded line to a process chamber, and the impedance of the apparatus may be changed depending on the manner of connecting them. In addition, Teflon used as a dielectric member for a high-power coaxial cable is expensive. For these reasons, the use of an RF power supply rod having a double-pipe structure, in place of a coaxial cable, has been considered.

FIG. **1** shows a conventional etching apparatus using such an RF power supply rod. An upper electrode **11** also serving as a gas supply portion and a lower electrode **10** having a susceptor **13** supported on a susceptor support base **12** are disposed in a process chamber **1** to oppose each other. An inner conductive rod **14** of the RF power supply rod is inserted from the lower side of the process chamber **1** to extend to the susceptor **13**, and an outer conductive pipe **15** of the RF power supply rod is connected to the bottom wall of the process chamber **1**. This bottom wall is electrically connected to the upper electrode **11** via the side wall of the process chamber **1**.

The lower end portions of the inner conductive rod **14** and the outer conductive pipe **15** are electrically connected to an RF power supply E and the ground via a matching circuit MC in a matching box M. The lower ends of the inner conductive rod **14** and the outer conductive pipe **15** are connected to the matching circuit MC via power supply rods **14***a* and **15***a*. Referring to FIG. **1**, reference numeral **16** denotes an exhaust pipe; **17** and **18**, insulating portions; and **19**, a cooling reservoir to which a cooling medium is circulated/supplied, and reference symbol W denotes a wafer as an object to be processed.

Below the process chamber **1**, there are a pipe for circulating/supplying a cooling medium such as liquid nitrogen to the refrigerant reservoir **19**, a gas inlet pipe (not shown) for supplying a backside gas to the lower surface of the wafer W, and the like. Therefore, the matching box M is located at a considerably lower position from the bottom wall of the process chamber **1**, and the RF power supply rod is considerably long. If the RF power supply rod is long, as described above, the axes of the inner conductive rod **14** and the outer conductive pipe **15** are sometimes greatly shifted from each other when they are coupled to the power supply rods **14***a* and **15***a* with screws or the like.

The sizes of wafers recently tend to increase from a conventional 6-inch wafer to 8- and 12-inch wafers. In addition, the liquid crystal panel techniques have advanced rapidly, and the sizes of panels tend to increase. Apparatuses for performing processes, e.g., film formation and etching, with respect to such LCD substrates have been developed.

When a plasma process, e.g., etching, is to be performed with respect to an object to be processed, e.g., a wafer or an LCD substrate having such a large size, a high voltage corresponding to an RF power of about 4 kW is required. In this case, in designing the apparatus, an RF power supply ratio must be set to have a predetermined characteristic impedance. Therefore, the ratio of the diameter of the inner conductive rod **14** to that of the outer conductive pipe **15** is determined on the basis of this characteristic impedance. For this reason, if the RF power increases, and the axes of the inner conductive rod **14** and the outer conductive pipe **15** are shifted and brought close to each other, a discharge may occur between the inner conductive rod **14** and the outer conductive pipe **15**.

If a discharge has occurred in the RF power supply rod, the supply efficiency of RF power decreases, resulting in a decrease in etching rate. In addition, the plasma becomes unstable, and impedance matching cannot be performed. As a result, a stable plasma process cannot be performed. In addition, the RF power supply rod itself is damaged by the discharge.

SUMMARY OF THE INVENTION

The present invention has been made in consideration of the above situation, and has as its object to provide a plasma process apparatus which can reliably prevent a discharge from occurring inside an RF power supply rod and which can perform impedance matching.

The object is achieved by a plasma process apparatus wherein RF power is applied to a process gas, thereby to convert the gas into plasma for processing an object, the apparatus comprising: a process chamber; an upper electrode located in the process chamber and having a gas-supplying section for supplying a process gas; a lower electrode located in the process chamber, having a cooling means, and opposing the upper electrode, for supporting an object; and RF power supplying means electrically connected to the lower electrode, protruding from the process chamber and connected to a RF power supply, for supplying RF power between the upper and lower electrodes, wherein the RF power supplying means includes an inner conductive rod, an outer conductive pipe surrounding the inner conductive rod and spaced therefrom, and a fixing member inserted between the inner conductive rod and the outer conductive pipe and having concaves and convexes, the inner conductive rod and the outer conductive pipe being electrically connected to an RF power supply source.

Additional objects and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and obtained by means of the instrumentalities and combinations particularly pointed out in the

appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate presently preferred embodiments of the invention and, together with the general description given above and the detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

FIG. **1** is a sectional view showing a conventional plasma process apparatus (etching apparatus);

FIG. **2** is a sectional view showing the overall arrangement of an etching apparatus (plasma process apparatus) according to an embodiment **1** of the present invention;

FIG. **3** is a sectional view showing a main part of the etching apparatus (plasma process apparatus) according to the embodiment **1** of the present invention;

FIG. **4** is a sectional perspective view showing a fixing member used in the embodiment **1** of the present invention;

FIG. **5** is a sectional view showing the overall arrangement of an embodiment **2** of the present invention;

FIG. **6** is a sectional view showing a joining structure of ground members in the embodiment **2** of the present invention;

FIG. **7** is a perspective view showing a joining member used for the joining structure;

FIG. **8** is a sectional view of the joining member used for the joining structure;

FIGS. **9**A and **9**B show views showing comparison tests of cases wherein a joining member is used and not used;

FIGS. **10** and **11** are sectional views showing the main part of another example of the embodiment **2** of the present invention;

FIG. **12** is a schematic circuit diagram showing the main part of a plasma process apparatus according to an embodiment **3** of the present invention;

FIG. **13** is an equivalent circuit diagram of a circuit for explaining the operation principle of a control section shown in FIG. **12**;

FIG. **14** is a chart showing a matched state obtained by the main part shown in FIG. **12**;

FIG. **15** is a chart showing a matched state obtained by a conventional matching circuit;

FIG. **16** is a circuit diagram for explaining a frequency conversion mechanism used for the main part shown in FIG. **12**;

FIG. **17** is a sectional view showing the overall arrangement of an embodiment **4** of the present invention;

FIG. **18** is a sectional view showing the main part of the embodiment **4** of the present invention;

FIG. **19** is a cutaway perspective view showing the main part of the embodiment **4** of the present invention;

FIG. **20** is a view showing the main part of another example the embodiment **4** of the present invention;

FIG. **21** is a schematic sectional view showing a plasma etching apparatus (plasma process apparatus) to which the embodiment **5** of the present invention;

FIG. **22** is a partial sectional view showing the arrangement of a power supply rod;

FIG. **23** is a sectional view showing the arrangement of a plasma process apparatus according to an embodiment **6** of the present invention;

FIG. **24** is an enlarged sectional view of a filter of a refrigerant supply system of the plasma process apparatus shown in FIG. **23**; and

FIG. **25** is an enlarged sectional view of a supply portion for a lower electrode of the refrigerant supply system of the plasma process apparatus shown in FIG. **23**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiment 1

An embodiment of the present invention will be described below. FIG. **2** is a schematic sectional view showing the overall arrangement of a plasma process apparatus, e.g., an etching apparatus, according to an embodiment **1** of the present invention. FIG. **3** is an enlarged sectional view of a main part of the embodiment. Gate valves **21** and **22** are arranged on the outer side wall of a process chamber **2** shown in FIG. **2** to airtightly seal a portion between the process chamber **2** and a load lock chamber (not shown). A susceptor support base **31** having, e.g., a columnar shape and consisting of a conductive metal, e.g., aluminum, is disposed at a central portion of the bottom surface of the process chamber **2**.

A susceptor **32** consisting of a conductive metal such as aluminum is fixed on the susceptor support base **31** with, e.g., bolts. In this case, a lower electrode is constituted by the susceptor support base **31** and the susceptor **32**. An electrostatic chuck sheet **33** is mounted on the upper surface of the susceptor **32**. The electrostatic chuck sheet **33** is formed by coating an insulating film consisting of, e.g., a polyimide film **35**, on the upper and lower surfaces of an electrode plate **34** consisting of, e.g., electrolytic copper foil. A wafer W is placed on the susceptor **32** via the electrostatic chuck sheet **33**.

A refrigerant reservoir **41** for circulating a cooling medium is formed in the susceptor support base **31**. Inlet and outlet pipes **41**A and **41**B are coupled to the refrigerant reservoir **41**. A cooling medium, e.g., liquid nitrogen, supplied into the refrigerant reservoir **41** via the inlet pipe **41**A is discharged via the outlet pipe **41**B. A ground member **43** which is continuous with a wall portion of the process chamber **2** is disposed via an insulating portion **42**.

A matching box **6** is arranged below the process chamber **1** via an RF power supply rod **5**. The RF power supply rod **5** has a double-pipe structure constituted by an inner conductive rod **51** made of a tubular member and an outer conductive pipe **52** which are concentrically arranged. Each member of the RF power supply rod **5** is made of a conductive material having a low resistivity, e.g., silver or copper, to efficiently supply RF power. If each member is made of copper, the surface of the member is plated with silver. The upper end portion of the inner conductive rod **51** is joined to the lower surface of the susceptor **32**, while the lower end portion of the inner conductive rod **51** is electrically connected to an RF power supply **61** via a matching circuit portion **60** including a blocking capacitor and the like arranged in the matching box **6**. A vent hole **51***a* is formed in the pipe wall of the inner conductive rod **51** to allow a dry gas to pass through, as will be described later.

The outer surface of the upper end portion of the outer conductive pipe **52** is, for example, threaded to be threadably engaged with and electrically connected to the bottom wall (the ground member **43**) of the process chamber **2**. In addition, an O-ring **50** (see FIG. **3**) is inserted between the outer conductive pipe **52** and the bottom wall. The lower end portion of the outer conductive pipe **52** is grounded via a

power supply rod **54** and the matching circuit portion **60**. An insulating ring **55** is inserted between the insulating portion **42**, the ground member **43**, and the inner conductive rod **51**. The lower end face of the insulating ring **55** is exposed to an inner space between the inner conductive rod **51** and the outer conductive pipe **52** to seal the upper end portion of the outer conductive pipe **52**. A recess portion **56** (see FIG. **3**) is formed in the exposure surface in the form of a ring to surround the inner conductive rod **51**.

A power supply line **62** extends through the inner conductive rod **51**. The lower end of the power supply line **62** is connected to a DC power supply **63** in the matching box **6** via a switch **64**, while the upper end of the power supply line **62** is electrically connected to the electrode plate **34** of the electrostatic chuck sheet **33**.

Fixing members **7** and **8** for fixing the relative positions of the inner conductive rod **51** and the outer conductive pipe **52** are respectively arranged between the inner conductive rod **51** and the outer conductive pipe **52** at two positions, i.e., near the middle position of the outer conductive pipe **52** in the longitudinal direction and at the lower end portion thereof above the power supply rod **54**. Each of these fixing members **7** and **8** made of a sintering member or the like is obtained by forming an insulating member, e.g., Teflon, into a ring and is fitted in the RF power supply rod **5** such that the outer surface of the fixing member is in contact with the inner surface of the outer conductive pipe **52**, and the inner surface of the fixing member is in contact with the outer surface of the inner conductive rod **51**.

As shown in FIGS. **3** and **4**, the fixing member **7** on the upper side has, for example, recess portions **71** formed in the upper and lower surfaces, at a position near the middle portion between the inner conductive rod **51** and the outer conductive pipe **52**, in the form of rings extending in the circumferential direction of the RF power supply rod **5**. A vent hole **72** is formed in the bottom surface of the recess portion **71** to extend through the fixing member **7**.

Similarly, a recess portion **81** is formed in the upper surface of the fixing member **8** on the lower side, and O-rings **82** and **83** are inserted between the inner conductive rod **51** and the outer conductive pipe **52** to airtightly seal a space above the fixing member **8** against the atmosphere.

A gas inlet pipe **91** and an exhaust pipe **92** respectively having valves V_1 and V_2 inserted therein are connected to the outer conductive pipe **52**. A gas source of a dry gas having a very low water content, e.g., SF_6 gas having good insulating properties, is connected to the upstream side of the gas inlet pipe **91**, whereas an exhaust means **93** is connected to the downstream side of the exhaust pipe **92**. Note that the exhaust means **93** may also serve as an exhaust means such as a vacuum pump for evacuating the process chamber **2**. In this case, the gas inlet pipe **91** and the valve V_1 are parts of a gas supply means. A constant pressure means ***52a*** is connected to the outer conductive pipe **52**.

An upper electrode **23** also serving as a gas supply portion is electrically connected to the side wall of the process chamber **2**, above the susceptor **32**, to oppose it. A gas supply pipe **24** for supplying a process gas, e.g., CHF_3 or CF_4, and an inert gas into the process chamber **2** is connected to the upper electrode **23**. In addition, a gas diffusion plate **25** for supplying a process gas into the process chamber **1** in the form of a shower is arranged on the lower surface of the upper electrode **23**. An exhaust pipe **26** connected to a vacuum pump (not shown) is arranged in a lower portion of the process chamber **2**. A plurality of gas supply pipes **24** and exhaust pipes **26** may be arranged in the process chamber **2** as shown in FIG. **3**.

The function of the above-described embodiment will be described next. First, the valve V_2 of the exhaust pipe **92** connected to the outer conductive pipe **52** is opened to evacuate the outer conductive pipe **52** by the exhaust means **93**. As described above, since the vent hole **72** is formed in the fixing member **7**, the space above the fixing member **7** is also evacuated. In addition, since the vent hole ***51a*** is formed in the inner conductive rod **51**, the inner conductive rod **51** is also evacuated via the vent hole ***51a***. For example, the pressure in the RF power supply rod **5** is reduced to about 10^{-2} Torr. The valve V_2 is then closed, and the valve V_1 is opened to supply a dry gas, e.g., SF_6 gas, from a gas source (not shown) into the RF power supply rod **5**. Thereafter, the valve V_1 is closed to set an atmosphere of SF_2 gas in the RF power supply rod **5** at about 2 kgf/cm^2.

The wafer W as an object to be processed is loaded into the process chamber **2** via the gate valve **21** by means of a convey arm (not shown), and is chucked/placed on the upper surface of the susceptor **32** via the electrostatic chuck sheet **33**. The upper surface of the susceptor **32** is cooled down to a predetermined temperature, e.g., about 0° C. to −100° C., by circulating, for example, liquid nitrogen in the refrigerant reservoir **41**. A process gas is supplied into the process chamber **2** via the gas supply pipe **24**, the upper electrode **23**, and the gas diffusion plate **25**. In addition, the process chamber **2** is evacuated via the exhaust pipe **26** to maintain a predetermined pressure in the process chamber **2**.

Meanwhile, for example, a 13.56-MHz, 1-kW RF power is applied through a loop constituted by the RF power supply **61**, the matching circuit portion **60**, the inner conductive rod **51**, the susceptor **32** (lower electrode), the upper electrode **23**, the wall portion of the process chamber **2**, the outer conductive pipe **52**, and the ground, thus generating a plasma between the upper electrode **23** and the susceptor **32**. With this plasma, an etching process is performed with respect to the wafer W. Note that the frequency of the RF power supply **61** may be set to be, e.g., 40 MHz. The wafer W which has undergone the plasma process is conveyed to a load lock chamber (not shown) by a convey arm (not shown) via the gate valve **22**.

According to the above-described embodiment, since ring-like fixing members **7** and **8** are arranged between the inner conductive rod **51** and the outer conductive pipe **52** at the two positions in the longitudinal positions, the axes of the inner conductive rod **51** and the outer conductive pipe **52** coincide with each other, and the distance therebetween remains the same at any positions in the longitudinal direction. That is, the inner conductive rod **51** and the outer conductive pipe **52** do not locally come close to each other. For this reason, there is no possibility that a discharge occurs through a space between the inner conductive rod **51** and the outer conductive pipe **52**. In addition, since the ring-like recess portions **71** and **81** are formed in the upper and lower surfaces of the fixing members **7** and **8**, the creeping distances of the fixing members **7** and **8** are large. Therefore, there is no possibility that discharges occur along the surfaces of the fixing members **7** and **8**.

A lower electrode **3** is cooled by a cooling medium, as described above, so that the RF power supply rod **5** is also cooled to a considerably low temperature. However, condensation can be prevented because SF_6 gas is sealed in the RF power supply rod **5**. Furthermore, SF_6 gas has good insulating properties. In consideration of these points, no discharge easily occurs between the inner conductive rod **51** and the outer conductive pipe **52**.

In the above-described arrangement, the number of fixing members in the RF power supply rod **5** may be properly determined in accordance with the length of the RF power supply rod **5** and the like. For example, the number of fixing members may be one or three or more. In addition, each fixing member need not be formed throughout the circumference, but may be formed around part of the circumference. In order to increase the creeping distance of each fixing member, a projection portion may be formed instead of the recess portion, or both projection and recess portions may be formed.

Embodiment **2**

FIG. **5** shows the overall arrangement of a plasma process apparatus according to an embodiment **2** of the present invention. Similar members to those shown in FIG. **2** will be designated by the same reference numerals and explanation thereof will be omitted. Referring to FIG. **5**, the ground member **43** is formed as a divided structure constituted by upper and lower members, i.e., a ground member **43A** on the bottom surface side and a ground member **43B** on the side surface side. A joining member **44** (to be described later) is inserted in the joined portion between the two ground members **43A** and **43B**. Similarly, the ground member **43A** on the bottom surface side is joined to a bottom wall portion **43C** of the vacuum chamber **2** via the joining member **44**.

An inner conductive rod **101** extends through central portions of the susceptor support base **31**, the insulating member **42**, and the ground member **43** (**43A**) from below the vacuum chamber **2**. The upper end of the inner conductive rod **101** is connected to the lower electrode **3**, while the lower end of the inner conductive rod **101** is connected to an RF power supply E via a blocking capacitor C in a matching box M. Note that an insulating member **101*a*** also serving as an airtight seal is interposed between the inner conductive rod **101**, the insulating member **42**, and the ground member **43**.

An outer conductive pipe **102** is arranged under the vacuum chamber **2** to enclose the inner conductive rod **101**. The upper end portion of the outer conductive pipe **102** is connected to ground member **43** (**43A**), while the lower end portion of the outer conductive pipe **102** is electrically connected to ground in the matching box M. The ground member **43B** is electrically connected to the side wall of the vacuum chamber **2** through a conductive member (not shown).

An electrostatic chuck sheet **105** is disposed on the surfaces of the lower electrode (susceptor) **3**. The electrostatic chuck sheet **105** is formed by sandwiching an electrode plate **103**, made of, e.g., a copper foil, between insulating sheets **104** consisting of, e.g., polyimide. The electrostatic chuck sheet **105** extends from an edge of the lower electrode **3** to its central portion along the lower surface. The electrode plate **103** is connected to a DC power supply **107** via a power supply line **106** extending through the inner conductive rod **101**.

The joining structure of the ground members **43A** and **43C** will be described below. As shown in the enlarged view of FIG. **6**, for example, recess portions **45** having the same shape are formed in the respective joining surfaces of the ground members **43A** and **43C** to oppose each other, and a Joining member **44** is fitted in the recess portions **45**. The joining member **44** is formed as follows. As shown in FIGS. **7** and **8**, two ends of a cylindrical member **47** consisting of, e.g., aluminum are bent inward, i.e., toward the central axis, and a middle portion of the cylindrical member **47** is caused to protrude outward in the form of a collar such that a protruding portion **46** has a U-shaped cross-section. In addition, four elongated notched portions a**1** to a4 are formed in the joining member **44** at equal angular intervals to extend from one end to portions slightly closer to the other end than the protruding portion **51** at the middle portion. Similarly, four notched portions b**1** to b4 are formed in the joining member **44** at equal angular intervals and at positions shifted from those of the notched portions a**1** to a4 by 45° in the circumferential direction so as to extend from the other end. Furthermore, for example, a silicone rubber **48** is sealed in the cylindrical member **47**, as shown in FIG. **9**.

A process performed with respect to a semiconductor wafer by the plasma process apparatus of the above-described embodiment and the function and effect of the joining structure of the ground members **43A** and **43B** will be described next.

A semiconductor wafer W as an object to be processed is loaded in the vacuum chamber **2** by a convey arm (not shown) via the gate valve **21** and is mounted on the wafer mount surface of the lower electrode (susceptor) **3** through a pusher pin (not shown). A process gas is supplied into the vacuum chamber **2** via the gas supply pipe **24** and the gas diffusion plate **25**, and the vacuum chamber **2** is evacuated by a vacuum pump (not shown) via the exhaust pipe **26**. While the vacuum chamber **2** is maintained at a predetermined internal pressure, an RF power of, e.g., 13.56 MHz and 1 kW is applied from the RF power supply E to a portion between the upper electrode **23** and the lower electrode **3** to generate a plasma. Reactive ions generated by this plasma are vertically incident on the surface of the semiconductor wafer W to cause a physical chemical reaction with a material (to be processed) on the wafer surface, thereby performing etching.

In this case, the RF current flows through the following loop: RF power supply E→inner conductive rod **101**→lower electrode **3**→plasma→upper electrode **23**→side wall of vacuum chamber **2**→ground member **43B** and bottom wall portion **43C** of vacuum chamber **2**→ground member **43A**→ outer conductive pipe **102**→RF power supply E. In this loop, conductive members are arranged to be dividable. For example, as shown in FIG. **5**, the ground members **43A** to **43C** are Joined to each other to be dividable. Owing to the use of the above-described joining member **44**, variations in RF impedance between a plurality of apparatuses are small, and the rate of change in RF impedance before and after division in one apparatus is low.

The cylindrical member **47** used for the joining member **44** has the notched portions (a**1** to a4 and b**1** to b4) formed in the axial direction and hence has a vertically divided structure. With this structure, the cylindrical member **47** is capable of contacting in the radial direction. In addition, since the two ends of the cylindrical member **47** are bent inward, and the middle portion protrudes, the cylindrical member **47** is extendible in the vertical direction. That is, the cylindrical member **47** is an elastic structure.

For this reason, for example, if the joining member **44** is made slightly larger in size than the recess portions **45** of the ground members **43A** and **43C** (or **43A** and **43B**) and is fitted therein against the elastic force of the joining member **44**, the outer surface is urged against the inner surfaces of the recess portions **45** by the elastic force (restoring force), thereby ensuring good surface contact.

The joining member **44** is not limited to the above-described structure in which the silicone rubber **48** is sealed in the cylindrical member **47**. However, if the silicone rubber **48** is sealed and fitted in the recess portions **45** while the cylindrical member **47** is caused to expand, as in the above embodiment, the respective surfaces are urged against

each other by the elastic effect of the silicone rubber **48**. Therefore, better surface contact can be ensured. Although the RF current flows in surface portions of the conductive members, variations in RF impedance between the joined portions of the conductive members are small, and the value of each RF impedance becomes small, because the entire surface of the joining member **44** is in surface contact with the conductive members.

As a result, the generation efficiency of RF power, i.e., the plasma state, does not change much before and after maintenance of the apparatus. Therefore, no adjustment is required. Even if adjustment is required, it is performed only in a narrow range, and no great change is required. In addition, when a large number of apparatuses are to be used, variations in characteristics of devices processed by the respective apparatuses can be suppressed. Furthermore, since the power efficiency improves, an energy-saving effect can be obtained.

The following model experiments were conducted to compare an impedance Z obtained when an RF current flowed in a case wherein the conductive members were joined to each other by using the above-described joining member **44** with that obtained in a case wherein the conductive members were Joined to each other with screws.

(Test 1)

As shown in FIG. **9**A, two aluminum blocks **110**A and **110**B, each having a cubic shape whose side is 3 cm long, were used. The blocks **110**A and **110**B were joined to each other by using the joining member **44** having silicone rubber sealed therein as in the above-described embodiment. The resultant structure was fixed with screws **111** at four corners, which screws were turned into the blocks in one direction. In this state, a 13.56-MHz voltage of 1 V was applied between the blocks **110**A and **110**B, and the impedances Z of the blocks **110**A and **110**B were measured. In addition, inductances L were obtained from these impedances Z. Note that the joining member **44** had a length of 40 mm and an outer diameter of 7.5 mm (the outer diameter of the protruding portion **46** was 9.0 mm, and the width of each of the notched portions (**a1** to a4 and b1 to b4) was 0.5 mm.

(Test 2)

Measurement was performed in the same manner as in Test 1 except that no silicone rubber was sealed in the joining member **44**.

(Test 3)

Measurement was performed in the same manner as in Test 1 except that the structure was not fixed with the screws **111**.

(Test 4)

As shown in FIG. **9**B, two aluminum blocks **110**A and **110**B, each having a cubic shape whose side was 3 cm long, (which were different from those shown in FIG. **9**A in that no recess portions allowing the joining member **44** to be fitted therein were formed) were used. These blocks were fixed with screws **111** at four corners, which screws were turned into the blocks in one direction. The impedances Z and the inductances L were measured in the same manner as in Test 1.

The results of Tests 1 to 4 are summarized in Table 1.

TABLE 1

	Test 1	Test 2	Test 3	Test 4
Z (mΩ)	21.85	34.48	45.35	52.69
L (pH)	152.33	161.37	448.13	609.12

Each of the above-mentioned results was obtained as an average value of a plurality of pairs of blocks. In Test 4 in which no joining member **44** was used, variations in impedance Z were larger than those in Tests 1 to 3 in which the joining member **44** was used. In addition, the value of the impedance Z was smaller when the joining member **44** was used than when the screws were used, and became smaller when silicone rubber was fitted in the joining member **44**.

In joining conductive member to each other, instead of placing the joining member **44** across the opposing joining surfaces of the blocks as in the above-described embodiment, recess portions **121** may be formed in side surfaces of conductive members **120**A and **120**B, and two end portions of a U-shaped Joining member **122** may be respectively fitted in the recess portions **81**, which end portions have, for example, an elastic structure like the one described in the above embodiment, as shown in FIG. **10**.

According to the present invention, instead of using the joining member **44** used in the above embodiment, a joining member **131** made of an elastic member having two ends formed into flat surfaces, e.g., a metal bellows, may be used in such a manner that the two end faces of the joining member **131** are urged against the bottom surfaces of recess portions **45** of conductive members **130**A and **130**B, as shown in FIG. **11**. With such a structure, since reliable surface contact can be obtained owing to the elastic force of the metal bellows, variations in impedance, i.e., variations in generation efficiency of RF power, can be reduced.

When such a metal bellows is to be used, a recess portion may be formed only in one of the joining surfaces of the conductive members, and the metal bellows may be fitted in the recess portion in such a manner that one end of the metal bellows is urged against the joining surface of the other conducive member to be in surface contact therewith.

A portion where the conductive members are joined to each other with a Joining member is not limited to the ground member at the position described in the above embodiment, and may be the upper electrode, the lower electrode, or a wall portion of the vacuum chamber. In addition, the present invention is not limited to an apparatus designed to generate a plasma in a vacuum chamber, and can be applied to an apparatus designed to generate a plasma in a gas supply path on the upstream side of a vacuum chamber and introduce the plasma into the vacuum chamber.

Embodiment **3**

FIG. **12** is a circuit diagram for explaining an RF power supply unit **140** used in a plasma process apparatus according to the embodiment **3** of the present invention.

The RF power supply unit **140** is constituted by an RF power supply section **141** and a matching section **142**.

An oscillation amplifier **143** having a specified frequency is arranged in the RF power supply section **141**. The specified frequency of this oscillation amplifier **16** can be updated by a signal from a control section (to be described later).

A detector **144** is arranged in the matching section **142**. The detector **144** serves to compare the output impedance (e.g., 50 Ω) of the oscillation amplifier **143**, which is equivalent to the output impedance of the RF power supply section **141**, with the input impedance of the matching section **142**. The detector **144** detects the difference between the output and input impedances and outputs the detection result to a control section **145**. Note that reference numeral **146** denotes a varactor. The capacitance of the varactor **146** is adjusted by a stepping motor **148** connected to a driver **147**. Reference numeral **149** denotes a blocking capacitor for preventing a DC current from flowing to the RF power supply section **141**.

The control section **145** performs matching of the impedances of the RF power supply section **141** and the matching section **142** as in the case of a matching circuit of this type. In this case, impedance matching is performed not only by reactance adjustment but also by adjustment of an oscillation frequency from the RF power supply section **141**.

FIG. **13** is an equivalent circuit diagram showing a matching circuit. In this circuit, an impedance (Z_0) which changes in accordance with the state of a plasma can be obtained by calculating the sum ($Z_0=Z_1+Z_2$) of an inductance component (Z_1), adjusted by a varactor C_2 for adjusting an inductance, and a capacitive reactance component (Z_2) of a varactor C_1. Therefore, the output impedance of the matching circuit may be set to be equal to the input impedance which changes in accordance with the state of a plasma. The following equation can be established with regard to the above-mentioned impedance (Z_0).

$$Z_1 = j(\omega L - 1/\omega C_2) \quad (1)$$

$$Y_2 = 1/R + j\omega C_2 \quad (2)$$

$$Z_2 = 1/Y_2 = 1/\{(1/R) + j\omega C_1\} \quad (3)$$

$$Z_0 = Z_1 + Z_2 \quad (4)$$

where R: input impedance (fixed value; 50 Ω)
L: coil
C_1: capacitor
C_2: capacitor

$$\begin{aligned} Z_0 &= j\{\omega L - 1/(\omega C_2)\} + 1/\{(1/R) + j\omega C_1\} \\ &= j\{\omega L - 1/(\omega C_2)\} + \{(1/R) + j\omega C_1\}/\{(1/R)^2 + (\omega C_1)^2\} \\ &= (1 + R)/\{(1/R)^2 + (\omega C_1)^2\} + j[(\omega L - 1/\omega C_2) - \omega C_1/\{(1/R)^2 + (\omega C_1)^2\}] \end{aligned}$$

where $\omega=2\pi f$.

Therefore, by changing the frequency (f), the impedance (Z_0) can be changed in accordance with the impedance of the load side which changes in accordance with the state of a plasma.

In this embodiment **3**, on the basis of this principle, the control section **145** performs impedance matching on the matching section **142** side by changing the oscillation frequency of the oscillation amplifier **143** in the RF power supply section **141** having an inductance component fixed, and the capacitance of the varactor C_1 for impedance matching in such a manner that the difference between the output impedance of the RF power supply side, detected by the detector **144**, and the input impedance of the matching section **142** side is nullified. As is apparent, in this case, when frequency conversion is performed, the phase difference is fixed.

In the embodiment having the above-described arrangement, the output impedance of the RF power supply section **141** side and the input impedance of the matching section **142** side are compared with each other by the detector **144**. If there is a difference between the impedances, frequency conversion in the oscillation amplifier **143** is performed through the control section **145** to nullify the difference. In addition, by replacing an inductance component with frequency conversion, the control section **145** performs capacitance adjustment only with respect to the matching varactor **146**.

When an experiment on impedance matching in this embodiment was conducted, the result shown in FIG. **14** was obtained.

FIG. **14** shows a case wherein the oscillation frequency from the RF power supply, which has been described in the embodiment, is converted. FIG. **15** shows a case wherein the oscillation frequency is fixed to, e.g., 13.56 MHz.

In the case shown in FIG. **14**, the frequency is changed, and the capacitance of the capacitor C_1 shown in FIG. **13** is variably changed while the capacitance of the capacitor C_2 is fixed. The frequency is changed within the range of 13.00 MHz to 14.00 MHz.

In the case shown in FIG. **15**, the capacitance of the capacitor C_1 shown in FIG. **13** is changed as a parameter, and the capacitance of the capacitor C_2 is changed within the range of 0 to 100% with reference to the capacitance of the capacitor C_1.

In this setting, capacitors are selected such that $C_1=0$ to 1,500 pF corresponds to 0 to 100%; and $C_2=0$ to 500 pF, 0 to 100%.

As is apparent from FIGS. **14** and **15**, in the embodiment in which frequency conversion is performed, a change in impedance can be realized in a range similar to that in the conventional matching method.

As has been described above, according to the embodiment, since the portion required to adjust the capacitance of a varactor can be reduced, relative drive control need not be performed unlike the case wherein control is performed with respect to a plurality of varactors. Therefore, the response speed at which predetermined impedances are matched can be increased.

The arrangement shown in FIG. **14** is available as an arrangement for converting the oscillation frequency of the RF power supply section **141**.

In the embodiment shown in FIG. **16**, a frequency synthesizer **153** constituted by a phase comparator **150**, a VCO **151**, and a frequency divider **152** is arranged on the output side of the RF power supply section **141**. In this case, the oscillation amplifier in the RF power supply section **141** is replaced with an arrangement (not shown) serving as a reference frequency oscillator. The phase comparator **150** compares the phase of a reference frequency with that of a reproduction output frequency from the frequency divider **152** to detect a phase difference. The phase difference is then input to the VCO **151**. The frequency divider **152** receives a correction signal from the control section **145** shown in FIG. **12**. Therefore, the output frequency reproduced by the frequency divider **152** is an output frequency capable of impedance matching, since the contents of the correction signal from the control section **145** correspond to the above-mentioned frequency used to perform impedance matching.

Embodiment 4

FIG. **17** is a schematic sectional view showing the overall arrangement of a plasma process apparatus such as an etching apparatus according to an embodiment **4** of the present invention. Similar members to those shown in FIG. **2** will be designated by the same reference numerals and explanation thereof will be omitted. A temperature monitor **36** constituted by, e.g., a fluoroptic thermometry and designed to detect the temperature of the susceptor support base **31** is arranged on the susceptor support base **31**.

A heating means, e.g., a heating wire **55**, is wound around the outer surface of the inner conductive rod **51** of the RF power supply rod **5**. The heating wire **55** is connected to a power supply section **57**, as shown in FIGS. **18** and **19**. The power supply section **57** is connected to a controller **37**. When, for example, a temperature detected by the temperature monitor **36** exceeds a predetermined value, the controller **37** performs control to decrease the power supplied to the controller **37** or turn off the power. Note that the controller

37 has a function of controlling the flow rate of a refrigerant and the like on the basis of a temperature detected by the temperature monitor 36.

A saucer 56 made of an insulating material is fitted on the lower end portion of the RF power supply rod 5. The saucer 56 serves to receive water drops falling via the pipe wall of the inner conductive rod 51 or the inner surface of the outer conductive pipe 52 and prevent the drops from falling in the matching box 6. For example, a partition wall 58 is formed on the saucer 56 to prevent the inner conductive rod 51 and the outer conductive pipe 52 from being short-circuited to each other via water remaining in the saucer 56.

The upper end portions of the power supply rods 53 and 54 are respectively coupled to the inner surfaces of the inner conductive rod 51 and the outer conductive pipe 52, and extend through the saucer 56. A power supply line 62 is also arranged in the inner conductive rod 51 to extend downward through a central projection portion 59 of the saucer 56. The lower end of the power supply line 62 is connected to a DC power supply 63, arranged in the matching box 6, via a switch 64. The upper end of the power supply line 62 is electrically connected to the electrode plate 34 of the electrostatic chuck sheet 33 at substantially the center of the lower side of the susceptor 32. For this purpose, part of the electrostatic chuck sheet 33 extends from the side wall of the susceptor 32 to the lower side, and an insulating film 35 is peeled off at substantially the center of the lower side of the susceptor 32 to expose the electrode plate 34.

The function of the above-described embodiment 4 will be described next. The semiconductor wafer W as an object to be processed is loaded into the process chamber 2 by a convey arm (not shown) via the gate valve 21, and is placed on the upper surface of the susceptor 3 via the electrostatic chuck sheet 33. A process gas is supplied into the process chamber 2 via the gas supply pipe 24, the upper electrode 25, and the gas diffusion plate 23. The process chamber 2 is then evacuated via the exhaust pipe 26 and is maintained at a predetermined internal pressure.

Meanwhile, for example, a 13.56-MHz, 1-kW RF power is applied through the following loop: RF power supply 61→matching circuit section 60→inner conductive rod 51→susceptor 32→upper electrode 25→wall portion of process chamber 2→outer conductive pipe 52→ground. With this application of the RF power, a plasma is generated between the upper electrode 25 and the susceptor 32, thus performing an etching process with respect to the semiconductor wafer W. Note that the frequency of the RF power may be set to be 40 MHz.

In this etching process, a DC voltage is applied from the DC power supply 63 in the matching box 6 to the electrode plate 34 via the switch 64, and the semiconductor wafer W is attracted/held on the susceptor 32 via the electrostatic chuck sheet 33 with the resultant electrostatic force. After the plasma process, the semiconductor wafer W is conveyed to a load lock chamber (not shown) by a convey arm (not shown) via the gage valve 22.

In this case, when the amount of a cooling medium supplied and the operation of a heater (not shown) are controlled on the basis of the monitoring operation of the temperature monitor 36, the temperature of the semiconductor wafer W on the susceptor 32 is controlled to become a desired temperature, e.g., −30° C. to −100° C.

When the susceptor support base 2 is cooled in this manner, the inner conductive rod 51, which is in contact with the susceptor support base 2, and the outer conductive pipe 52 (via the inner conductive rod 51) are also cooled. As a result, condensation occurs on the surfaces of the inner and outer walls of the inner conductive rod 51 and the outer conductive pipe 52. In order to suppress this condensation, the heating wire 55 is energized to generate heat.

In this case, since the heating wire 55 is wound around the outer surface of the inner conductive rod 51, the heat is transferred to the outer conductive pipe 52 via the inner space of the double-pipe structure so as to heat the outer conductive pipe 52. Therefore, the overall RF power supply rod 5 can be effectively heated to prevent condensation. Even if condensation actually occurs, moisture can be evaporated and removed. Furthermore, if the amount of condensation is large, and water drops flow downward via the wall surfaces of the inner conductive rod 51 and the outer conductive pipe 52, these water drops are stored in the saucer 56 arranged on the lower side of the RF power supply rod 5 and are evaporated and removed by, for example, heat generated by the heating wire 55.

In this case, when such a heating operation is to be performed, it is important that the temperature of the susceptor support base 31 does not exceed a preset temperature. An area where the heating wire 55 is wound and the energization amount are determined in consideration of such a point. Various methods can be employed to control power supply to the heating wire 55. If, for example, control of the energization amount or ON/OFF control is performed on the basis of a temperature detected by the temperature monitor 36 as in the above-described case, temperature control of the susceptor 3 is not influenced.

As described above, in the etching apparatus of this embodiment, since the heating wire 55 is provided for the RF power supply rod 5 to heat it, condensation on the RF power supply rod 5 can be prevented when the susceptor support base 31 is cooled. In addition, even if condensation has occurred, moisture can be evaporated and removed. Furthermore, since the saucer 56 is arranged on the lower side of the RF power supply rod 5, the condensed drops can be prevented from falling in the matching box 6.

In the above-described case, heating wires may be wound around both the inner conductive rod 51 and the outer conductive pipe 52. As a heating means, a means for radiating heat to the RF power supply rod 5 may be used instead of a heating wire. Furthermore, if water drops flow on the outer surface of the outer conductive pipe 52, the saucer 56 may be designed to have a larger outer diameter than the outer conductive pipe 52 so as to receive the water drops.

The another example of the embodiment 4 will be described next. As shown in FIG. 20, one end of a gas inlet pipe 161 is connected to a gas source (not shown) of a gas having a low dew point, e.g., SF_6, and the other end of the gas inlet pipe 161 is connected to an outer conductive pipe 52 of an RF power supply rod 5 via an opening/closing valve 162. In addition, an exhaust means 164 is connected to the outer conductive pipe 52 via an opening/closing valve 163. In this case, a gas introduction means is constituted by the gas source and the gas inlet pipe 161. As the exhaust means 164, for example, a vacuum pump or the like for evacuating a process chamber 2 is commonly used. Note that the opening/closing valves 162 and 163 are controlled by a controller 37.

The function of this embodiment will be described below. The opening/closing valve 163 is opened by a control signal from the controller 37, and the inner space of the inner conductive rod 51 of the RF power supply rod 5 and the space between the inner conductive rod 51 and the outer conductive pipe 52 are evacuated by the exhaust means 164 to set a reduced-pressure atmosphere, e.g., 10^{-2} Torr or less. Thereafter, the opening/closing valve 163 is closed, while

the opening/closing valve **162** is opened by a control signal from the controller **37** to introduce, e.g., an SF_6 gas into the RF power supply rod **5**. In this case, the SF6 gas is also introduced into the inner conductive rod **51** via the gas inlet port **165** to fill the entire inner space of the RF power supply rod **5**. With this operation, the RF power supply rod **5** is set at almost atmospheric pressure or more, e.g., 2 kgf/cm^2 by using the low-dew-point gas (dry gas).

As described above, in this embodiment, a low-dew-point gas atmosphere is set in the RF power supply rod **5** to suppress adhesion of moisture to the surfaces of the inner conductive rod **51** and the outer conductive pipe **52**, thereby preventing condensation of moisture on the RF power supply rod **5** when a susceptor support base **31** is cooled. Therefore, this embodiment has the same effects as those of the example described above. In addition, if a heating means is also used the heating means as shown in FIG. **17**, condensation can be more efficiently prevented. A low-dew-point gas is not limited to an SF_6 gas. For example, air containing a very small amount of moisture may be used. Furthermore, a gas may be caused to circulate inside/outside the RF power supply rod **5**, and this gas may be dried outside to be returned to the RF power supply rod **5**.

Embodiment 5

FIG. **21** is a schematic sectional view showing a plasma etching apparatus to which embodiment **5** of the present invention. Similar members to those shown in FIG. **2** will be designated by the same reference numerals and explanation thereof will be omitted.

In FIG. **21**, the susceptor support base **31** has a temperature monitor **36**, e.g., a fluoroptic thermometer. A temperature signal from the temperature monitor **36** is connected to a controller **37**, and the amount of liquid nitrogen supplied to the refrigerant reservoir **41** is controlled by the controller **37**. In addition, a heater (not shown) is controlled to control the temperature of the semiconductor wafer W to, e.g., 10° C. to −150° C., as needed.

In order to supply RF power having a frequency of, e.g., 13.56 MHz or 40.68 MHz and an output power of, e.g., 200 W to 3 kW to the susceptor **32** and the susceptor support base **31**, an RF power supply rod **5** is arranged under the susceptor **32** to extend through an insulating ring **55**, which is insulated from the process chamber **2** and airtightly seals it, and the susceptor support base **31**. As shown in FIG. **22**, the RF power supply rod **5** has a double-pipe structure constituted by an outer conductive pipe **52** serving as an outer pipe on the ground side and an inner conductive rod **51** serving as an inner pipe for applying RF power. A hollow portion **171*a*** is formed between the inner conductive rod **51** and outer conductive pipe **52**, and a hollow portion **171*b*** is formed in the inner conductive rod **51**.

In order to efficiently supply RF power, the inner conductive rod **51** is made of a conductive material having a low resistivity, e.g., silver or copper. If the inner conductive rod **51** is made of copper, the copper surface is plated with silver.

Sealing portions **172**, each made of, e.g., a ceramic or Teflon, are arranged to provide insulation and seals for the lower end portions of the inner conductive rod **51** and outer conductive pipe **52** between the inner conductive rod **51** and outer conductive pipe **52** and in the inner conductive rod **51**.

A gas inlet pipe **91** for introducing an inert gas, e.g., N_2, into the hollow portion **171*a*** is formed in the outer conductive pipe **52** via an valve V_1, e.g., an electromagnetic valve. A hole **51*a*** is formed in the inner conductive rod **51** to introduce the inert gas into the inner conductive rod **51** via the hollow portion **171*b*** formed between the inner conductive rod **51** and outer conductive pipe **52**.

In addition, an exhaust pipe **92** for evacuating the hollow portions **171*a*** and **171*b*** is formed in the outer conductive pipe **52**. The exhaust pipe **92** is connected to an evacuation means, e.g., an exhaust means **93**, via an valve V_2. The valve V_1 and V_2 are ON/OFF-controlled by a control signal from the controller **37**. The outer conductive pipe **52** is arranged to enclose the inner conductive rod **51** and is connected to a bottom portion of the process chamber **2**. Therefore, the outer conductive pipe **52** also serves as an RF shield. The inner conductive rod **51** is connected to an RF power supply E via a blocking capacitor C. The RF power supply E is ON/OFF-controlled by a control signal from the controller **37**. The susceptor **32** and the side and bottom surfaces of the susceptor support base **31** are arranged to be covered with insulating members, e.g., ceramic members.

The electrostatic chuck sheet **33** extends to a substantially central portion between the susceptor **32** and the susceptor support base **31** along a side wall of the susceptor **32**. At this substantially central portion, the polyimide film **35** of the electrostatic chuck sheet **33** is peeled off to expose the electrolytic copper foil. A power supply line **62** for applying a DC voltage, e.g., a voltage of 3 kV or less, is in contact with a power supply portion **62*a***. The power supply line **62** extends through the inner conductive rod **51**. A coil **66** is series-connected to the power supply line **62** via a switching means, e.g., an electromagnetic switch **69**. A capacitor **68** is connected between the coil **66** and the ground in parallel with a DC power supply **67**. The electromagnetic switch **69** is ON/OFF-controlled by the controller **37**. Note that the coil **66** has a high inductance with respect to the above-mentioned RF power to have a high electric resistance with respect to the RF power.

As shown in FIG. **21**, an upper electrode **23** as a counterelectrode is disposed above the susceptor **32** in the upper portion of the process chamber **2**. A process gas, e.g., CHF_3 or CF_4, or an inert gas is supplied to the upper electrode **23** via a gas supply pipe **24** and an opening/closing valve **27**. The process gas is then blown toward the semiconductor wafer via a plurality of holes **28** formed in the bottom wall of the upper electrode **23**. When the RF power supply E is turned on, a plasma is generated between the upper electrode **23** and the semiconductor wafer W. The upper electrode **23** is grounded by a wire **29** to be electrically grounded.

The susceptor **32** also has a pin (not shown) which is electrically grounded through a resistor or an inductance and can be moved vertically. This pin is vertically moved when the semiconductor wafer W is conveyed by the convey unit in the load lock chamber, and the semiconductor wafer W is placed or released on or from the chuck surface of the electrostatic chuck sheet **33**.

An exhaust pipe **26** for evacuating the process chamber **2** is formed in a bottom portion of a side wall of the process chamber **2**. The exhaust pipe **26** is connected to the exhaust means **93** via an opening/closing valve (not shown), e.g., a butterfly valve, thus constituting a plasma etching apparatus.

A function for setting the power supply rod in an inert gas atmosphere or a reduced-pressure atmosphere in the plasma etching apparatus having the above-described arrangement will be described below.

The above-mentioned inert gas is introduced into the hollow portion **171*a*** between the inner conductive rod **51** and outer conductive pipe **52** and into the hollow portion **171*b*** in the inner conductive rod **51** in the following manner. First, the valve V_2 is turned on by a control signal from the controller **37** to set a reduced-pressure atmosphere, e.g., 10^{-2} Torr or less, in the hollow portions **171*a*** and **171*b*** by using the exhaust means **93** when the apparatus is started.

The valve V_2 is then turned off, and the valve V_1 is turned on by a control signal from the controller **37**, thus introducing an inert gas, e.g., an N_2 gas, into the hollow portion **171***a*.

The inert gas introduced into the hollow portion **171***a* is also introduced into the hollow portion **171***b*, formed in the inner conductive rod **51**, via the gas supply pipe **91** formed in the inner conductive rod **51**. As a result, in the hollow portions **171***a* and **171***b*, a highly pure inert gas atmosphere having almost atmospheric pressure or more, e.g., 2 kgf/cm^2 and containing no moisture is set.

Since an inert gas atmosphere is set between the ground side and RF power application side of the RF power supply rod, the amount of moisture in the air which adheres to the RF power supply rod can be reduced, thereby suppressing corrosion of the RF power supply rod.

When the temperature of the susceptor is to be set to −30° C. or less by a cooling medium, e.g., liquid nitrogen, condensation of moisture in the atmosphere on the surfaces of the supply and ground pipes can be suppressed. In addition, since corrosion of the supply and ground pipes and condensation thereon can be suppressed, the efficiency of supplying RF power to the susceptor can be stabilized, thereby suppressing variations in process of objects to be processed and increasing the yield of objects to be processed.

In this embodiment, N_2 is used as an inert gas. It is, however, apparent that a rare gas, e.g., He, Ne, Ar, Kr, Xe, or Rn may be used as long as it is an inert gas. In addition, it is obvious that a reduced-pressure atmosphere may be maintained in the power supply rod without introducing an inert gas. Furthermore, it is obvious that an inert gas may be caused to circulate in the power supply rod by the inert gas inlet means and the exhaust means. An inert gas may be supplied to substitute the atmosphere with an inert gas atmosphere without using the evacuation means. The present invention is not limited to the above-described embodiment. Various changes and modifications can be made within the spirit and scope of the invention.

Embodiment **6**

An embodiment **6** of the present invention will be described below with reference to FIGS. **23** to **25**. As shown in FIG. **23**, a process apparatus of the embodiment **6** comprises a process chamber **2** consisting of a conductive material such as aluminum, a lower electrode **3** arranged on the bottom surface of the process chamber **2** and also serving as a mount table on which a semiconductor wafer W as an object to be processed is mounted, and an upper electrode **23** arranged above the lower electrode **3** at a distance of, e.g., 15 to 20 mm. A refrigerant supply system **180** and a gas exhaust system **190** (both will be described later) are connected to the lower electrode **3**. With this arrangement, when the semiconductor wafer W is to be processed, for example, liquid nitrogen L is supplied to the lower electrode **3** by the refrigerant supply system **180** to constantly cool the lower electrode **3**, and a nitrogen gas produced upon this cooling operation is exhausted by the gas exhaust system **190**.

An exhaust unit (not shown) is connected to the process chamber **2** via an exhaust pipe **26**. With this exhaust unit, a reduced-pressure atmosphere, e.g., 10^{-2} Torr or less, is set in the process chamber **2**. In addition, an RF power supply E is connected to the lower electrode **3** via a capacitor C. RF power is applied from the RF power supply E to the lower electrode **3** to form an etching gas such as CF_4 into a plasma between the lower electrode **3** and the grounded upper electrode **23**, thus producing active species such as ions and radicals. The upper electrode **23** has a hollow portion. A gas supply pipe **24** for supplying an etching gas into the hollow portion is connected to the upper surface of the upper electrode **23**. A plurality of holes **28** for blowing the etching gas are distributively formed in the lower surface of the upper electrode **23**. The etching gas is supplied into the process chamber **2** via the plurality of holes **28**, and the semiconductor wafer W is etched by active species such as ions and radicals produced by a discharge between the lower electrode **2** and the upper electrode **23**.

As shown in FIG. **23**, the refrigerant supply system **180** comprises a supply pipe **181** serving as a supply path for the liquid nitrogen L from a liquid nitrogen bomb, and a driving mechanism, e.g., an electromagnetic valve **182**, arranged in the supply pipe **181** and designed to adjust the flow rate of the liquid nitrogen L to a predetermined amount. The supply pipe **181** is designed to have a double-pipe structure constituted by a stainless steel inner pipe **181**A and a stainless steel outer pipe **181**B as shown in FIG. **25**. A filter **183** is provided for the inner pipe **181**A to be located on the upstream side of the electromagnetic valve **182**. FIG. **24** is an enlarged view of the filter **183**. Referring to FIG. **24**, the filter **183** is elastically interposed between coupling members **183**A and **183**B of the inner pipe of the supply pipe **181** via a coil spring **183**C. The liquid nitrogen L flowing from the left is filtered by the filter **183** to stop particle-like substances such as frozen particles (e.g., fine frozen particles of water) contained in the liquid nitrogen L, and is then made to flow to the right, thereby preventing the fine frozen particles from adhering to the inner wall of the electromagnetic valve **181** and the driving portion located on the downstream side of the filter **183**, or preventing fine frozen particles adhering to the electromagnetic valve **181** from growing and interfering with the operation of the electromagnetic valve **181**. In addition, the filter **183** serves to prevent fine frozen particles from adhering to and growing on the inner wall of the inner pipe **181**A located on the downstream side of the filter **183**. If the gas pressure in a cooling block **200** rises abnormally, the gas pressure is absorbed by the coil spring **183**C. The filter **183** is made of a sintered metal such as bronze or stainless steel as an assembly of many capillaries communicating with each other, and is designed to stop particle-like substances in the liquid nitrogen L and allow only the liquid nitrogen L to pass, as described above.

The downstream end of the supply pipe **181** is located at a position where it protrudes from the liquid surface of the liquid nitrogen L in a refrigerant reservoir portion **200**A of the cooling block **200**. A gas/liquid separating member **184** made of a sintered metal formed in the same manner as that for the filter **183** is mounted at the downstream end of the supply pipe **181**. A nitrogen gas which is produced when the liquid nitrogen is gasified in the process of flowing through the supply pipe **181** is separated from the liquid nitrogen in the gas/liquid separating member **184** in the refrigerant reservoir portion **200**A. The nitrogen gas is then dispersed in the space above the liquid nitrogen L, and the liquid nitrogen L is supplied smoothly so as not to disturb the liquid surface of the liquid nitrogen L.

The gas/liquid separating member **184** is formed to have a cylindrical shape with its upper end being closed. The lower end of the gas/liquid separating member **184** is coupled to the downstream end of the inner pipe **181**A of the supply pipe **181** via an upper coupling member **184**A, a lower coupling member **184**B, and a pressure reducing double pipe **184**C so as to prevent heat from entering from a portion near the downstream end of the supply pipe **181**. The pressure reducing double pipe **184**C is constituted by an

inner pipe **184D** made of a material, e.g., a ceramic material, having a small thermal expansion coefficient and excellent electrical insulating properties, an outer pipe **184E** made of the same material as that for the inner pipe **184D**, and a sealing member **184F** for sealing the lower end of a space defined between the pipes **184D** and **184E**. With this arrangement, the space between the inner and outer pipes **184D** and **184E** is evacuated upon communication with the process chamber **2**, and the interior of the inner pipe **184D** serves as a supply path for the liquid nitrogen L.

An exhaust pipe **191** of the gas exhaust system **190** has a pressure reducing double pipe (not shown) having the same arrangement as that of the pressure reducing double pipe **184C**. The upstream end of the exhaust pipe **191** is located at a position where it protrudes from the liquid surface of the liquid nitrogen L stored in the refrigerant reservoir portion **200A**, as shown in FIG. **23**, so as to exhaust a nitrogen gas formed upon gasification of the liquid nitrogen in the refrigerant reservoir portion **200A**. In addition, a level meter (not shown) for monitoring the level of the liquid nitrogen L is arranged in the refrigerant reservoir portion **200A**. The electromagnetic valve **182** of the refrigerant supply system **180** is ON/OFF-controlled on the basis of a monitoring result obtained by the level meter, thus always holding a predetermined amount of the liquid nitrogen L in the refrigerant reservoir portion **200A** as the liquid nitrogen L is consumed.

The operation of the embodiment will be described next. The semiconductor wafer W is placed on the lower electrode **3** in the process chamber **2** which is set in a reduced-pressure state of, e.g., 10^{-2} Torr or less. RF power is then applied to the lower electrode **3** to form a discharge space between the lower and upper electrodes **3** and **23**. At the same time, an etching gas is supplied into the process chamber **2** via the gas supply pipe **24** of the upper electrode **23**. As a result, the etching gas is formed into a plasma in the process chamber **2**, and the semiconductor wafer W is etched by the resultant active species.

When the liquid nitrogen L is consumed as the semiconductor wafer W is cooled by the cooling block **200** during the etching process with respect to the semiconductor wafer W, and the liquid surface lowers, the level meter detects the liquid level. The electromagnetic valve **182** is then opened on the basis of the detection result so as to replenish the refrigerant reservoir portion **200A** with the liquid nitrogen L, thereby always holding a predetermined amount of the liquid nitrogen L in the refrigerant reservoir portion **200A**. In this case, even a small amount of moisture contained in the liquid nitrogen L will be frozen to become fine frozen particles, and the particles will flow in the refrigerant supply system **180**. However, such fine frozen particles are reliably stopped by the filter **183**, and the liquid nitrogen flows to the downstream side of the filter **183** to reach the electromagnetic valve **182**. In this case, unlike the prior art, there is no possibility that the valve mechanism clogs with fine frozen particles to interfere with the operation of the electromagnetic valve **182**. Therefore, the flow of the liquid nitrogen L can always be controlled by the electromagnetic valve **182** accurately to reliably supply the liquid nitrogen L into the refrigerant reservoir portion **200A**, thereby always controlling the temperature of the semiconductor wafer W on the lower electrode **3** to a predetermined temperature. In addition, even if fine particles such as dust enter the supply pipe **181** and the like between the source of the liquid nitrogen L and the filter **183**, such fine particles can be reliably removed.

Assume that in the refrigerant reservoir portion **200A**, the liquid nitrogen L produces a nitrogen gas, owing to heat transferred to the supply pipe **183**, while passing through the supply pipe **183**. Even in such a case, since the nitrogen gas is temporarily stored in the space in the gas/liquid separating member **184** and is quickly dispersed into the refrigerant reservoir portion **200A** via the capillaries of the gas/liquid separating member **184**, and at the same time, the liquid nitrogen L is caused to flow into the refrigerant reservoir portion **200A** via the capillaries of the gas/liquid separating member **184**, the liquid nitrogen L can be quietly supplied along the circumferential surface of the downstream end of the supply pipe **181** without disturbing the liquid surface of the liquid nitrogen L, and the amount of the liquid nitrogen L can be accurately detected by the level meter to always hold a predetermined amount of the liquid nitrogen L in the refrigerant reservoir portion **200A**. With this operation, a stable process can be performed with respect to the semiconductor wafer W.

As described above, according to the process apparatus of the embodiment, the filter **183** consisting of a sintered metal is arranged on the upstream side of the electromagnetic valve **182** of the supply pipe **181** of the refrigerant supply system **180**, and the downstream end of the supply pipe **181** is placed in the refrigerant reservoir portion **200A**. In addition, the gas/liquid separating member **184** consisting of a sintered metal is arranged on the downstream end of the supply pipe **181**. with this arrangement, particle-like substances, e.g., fine frozen particles, contained in the liquid nitrogen L can be removed by the filter **183** on the upstream side of the driving portion, i.e., the electromagnetic valve **182**, arranged midway along the supply path for the liquid nitrogen L, thus reliably driving the electromagnetic valve **182** and reliably supplying the liquid nitrogen L to the cooling block **200** by a predetermined flow rate. In addition, a nitrogen gas can be reliably separated from the liquid nitrogen L by the gas/liquid separating member **184** in the refrigerant reservoir portion **200A** so as to quietly supply the liquid nitrogen L to the liquid surface of the stored liquid nitrogen L, thereby always holding a stable liquid surface and reliably managing the liquid surface of the liquid nitrogen L. With this operation, a stable process can always be performed with respect to the semiconductor wafer W at a predetermined low temperature.

The present invention is not limited to an etching apparatus and may be applied to a heat treatment apparatus such as a plasma CVD apparatus, an ashing apparatus, and the like as long as the apparatuses are designed to supply power through an RF power supply rod **5** and perform a plasma process with respect to an object to be processed, e.g., a semiconductor wafer and an LCD substrate. Note that since an RF power supply rod may cause condensation owing to moisture in the open air, the present invention can be applied to a case wherein no refrigerant reservoir is arranged in a susceptor support base. As a dry gas, a gas other than SF**6**, e.g., an inert gas such as a nitrogen gas, or air from which moisture is sufficiently removed, may be used.

According to the invention a discharge in the RF power supply rod can be prevented, a reduction in RF power supply efficiency can be suppressed and an impedance matching can be performed.

According to the invention condensation in the RF power supply rod can be prevented, thereby further reliably preventing a discharge in the RF power supply rod. In addition, corrosion of the RF power supply rod can be prevented.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, and representative devices shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

1. A plasma process apparatus wherein RF power is applied to a process gas, thereby to convert the gas into plasma for processing an object, said apparatus comprising:

a process chamber;

an upper electrode located in said process chamber and having a gas-supplying section for supplying a process gas;

a lower electrode located in said process chamber, having a cooling means, and opposing said upper electrode, for supporting an object; and

RF power supplying means electrically connected to said lower electrode, protruding from said process chamber and connected to a RF power supply, for supplying RF power between said upper and lower electrodes,

wherein said RF power supplying means includes an inner conductive rod, an outer conductive pipe surrounding said inner conductive rod and spaced therefrom, and a fixing member inserted between said inner conductive rod and said outer conductive pipe and having concaves and convexes, said inner conductive rod and said outer conductive pipe being electrically connected to an RF power supply source.

2. The apparatus according to claim 1, wherein said fixing member extends along said inner conductive rod, and said concaves and convexes are formed at that portion of said fixing member which is exposed to a space defined by said inner conductive rod and said outer conductive pipe.

3. The apparatus according to claim 1, wherein that portion of said process chamber which is covered with an insulating member and which supports said lower electrode is formed of a plurality of members each having a concave, which are fastened together by fastening members fitted in the concaves of said members.

4. The apparatus according to claim 3, wherein each of said fastening members is made of an elastic body covered with a metal layer.

5. The apparatus according to claim 4, wherein each of said fastening member is in full contact with inner surfaces of the concaves of said members, due to a restoring force of said elastic body.

6. The apparatus according to claim 1, further comprising gas-introducing means for introducing dry gas into a space defined by said inner conductive rod and said outer conductive pipe.

7. The apparatus according to claim 1, further comprising heating means for heating said RF power supplying means.

8. The apparatus according to claim 1, further comprising an electrically insulating vessel connected to said RF power supplying means, for receiving water drops generated in said RF power supplying means.

9. The apparatus according to claim 1, further comprising exhaustion means secured to said outer conductive pipe, for reducing pressure in a space defined by said inner conductive rod and said outer conductive pipe.

10. A plasma process apparatus wherein RF power is applied to a process gas, thereby to convert the gas into plasma for processing an object, said apparatus comprising:

a process chamber;

an upper electrode located in said process chamber and having a gas-supplying section for supplying a process gas;

a lower electrode located in said process chamber, having a cooling means, and opposing said upper electrode, for supporting an object;

RF power supplying means electrically connected to said lower electrode, protruding from said process chamber and connected to a RF power supply, for supplying RF power between said upper and lower electrodes; and

impedance matching means for detecting an impedance difference between said RF power supply and said lower electrode and for adjusting at lest a variable capacitance, to thereby perform impedance matching,

wherein said RF power supply includes a frequency changing section for changing an output frequency, and a control section for performing impedance matching by controlling the output power frequency, together with the variable capacitance, in accordance with the impedance difference detected between said RF power supply and said lower electrode, and said process chamber has a portion which is covered with an insulating member and which supports said lower electrode, said portion being formed of a plurality of members each having a concave, which are fastened together by fastening members fitted in the concaves of said members.

11. The apparatus according to claim 10, wherein said RF supply means includes an inner conductive rod, and an outer conductive pipe surrounding said inner conductive rod, said inner conductive rod and said outer conductive pipe being electrically connected to an RF power supply source.

12. The apparatus according to claim 11, wherein each of said fastening members is made of an elastic body covered with a metal layer.

13. The apparatus according to claim 12, wherein each of said fastening member is in full contact with inner surfaces of the concaves of said members, due to a restoring force of said elastic body.

14. The apparatus according to claim 11, further comprising gas-introducing means for introducing dried gas into a space defined by said inner conductive rod and said outer conductive pipe.

15. The apparatus according to claim 11, further comprising exhaustion means secured to said outer conductive pipe, for reducing pressure in a space defined by said inner conductive rod and said outer conductive pipe.

16. The apparatus according to claim 10, further comprising heating means for heating said RF power supplying means.

17. The apparatus according to claim 10, further comprising an electrically insulating vessel connected to said RF power supplying means, for receiving water drops generated in said RF power supplying means.

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